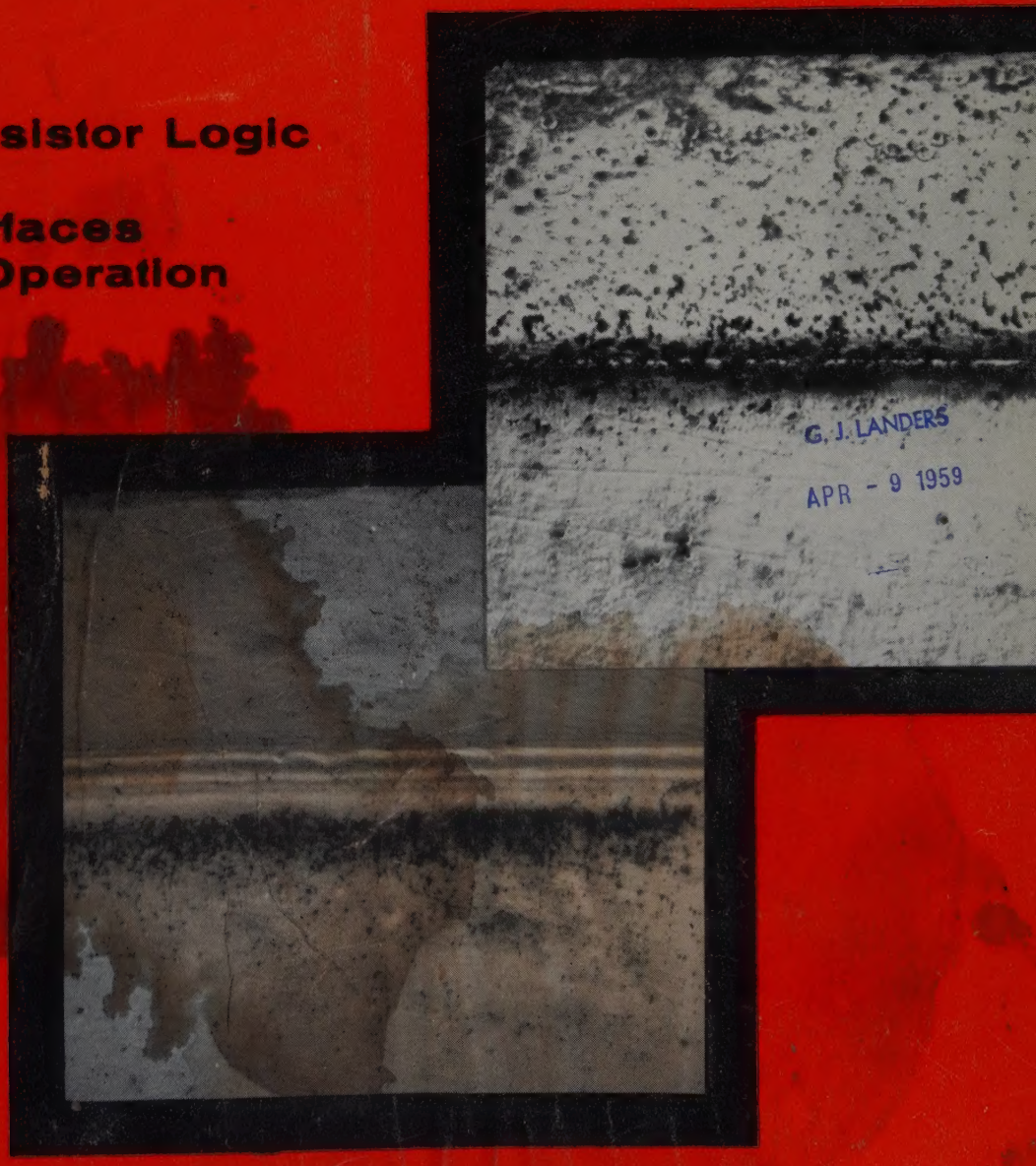
April 1959
75¢

# EMICONDUCTOR PRODUCTS

Transistor Resistor Logic

Effects of Surfaces on Device Operation

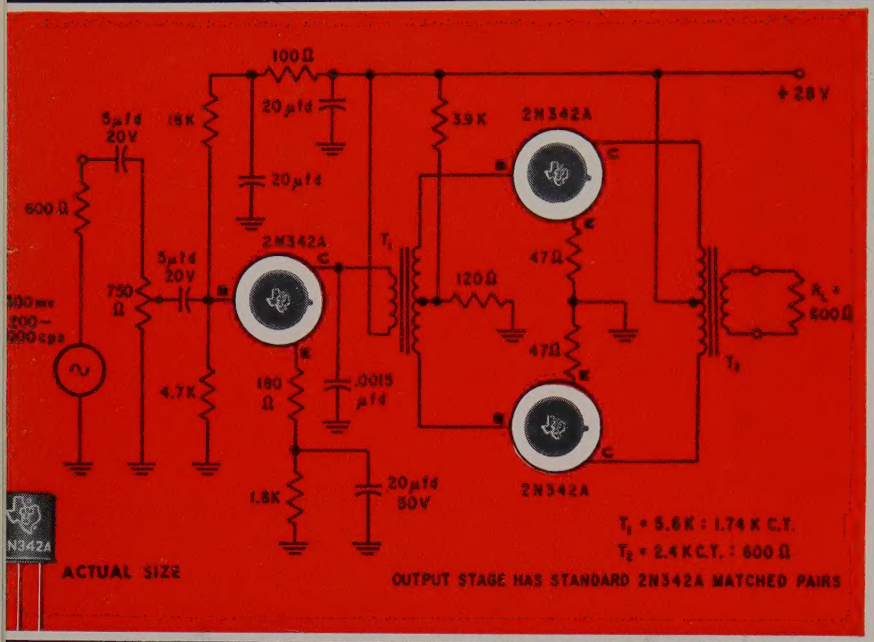



crophotograph of
Areas in the Vi-
nity of an Arsenic
sed P-N Junction

Effects of Impurity Distributions

Advantages of Tetrode Geometry

# TRANSISTORIZED INTERCOM EXCEEDS MIL-E-5272B SPECS!




## CIRCUIT SPECIFICATIONS

150-mw output from -55°C to 100°C at less than 10% harmonic distortion over frequency range

Frequency response @ 25°C stable within ±2 db of 1000 cps 100 mw reference level from 200 to 8000 cps

Frequency response @ -55°C and 100°C within ±3 db of 25°C frequency response

Less than 3-db gain variation @ -55°C and 100°C compared to 25°C measurement

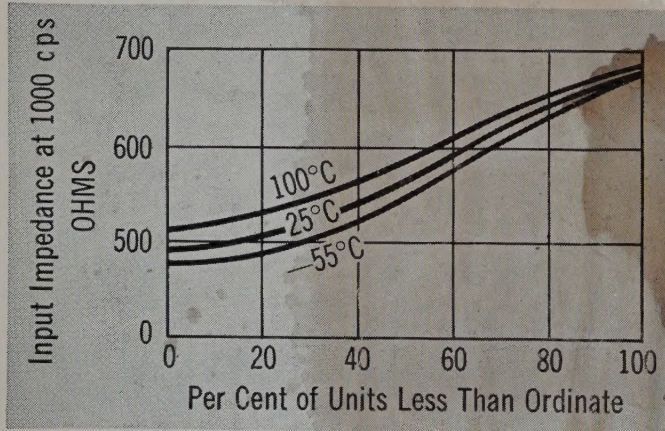
# LOUD AND CLEAR AT 100°C!

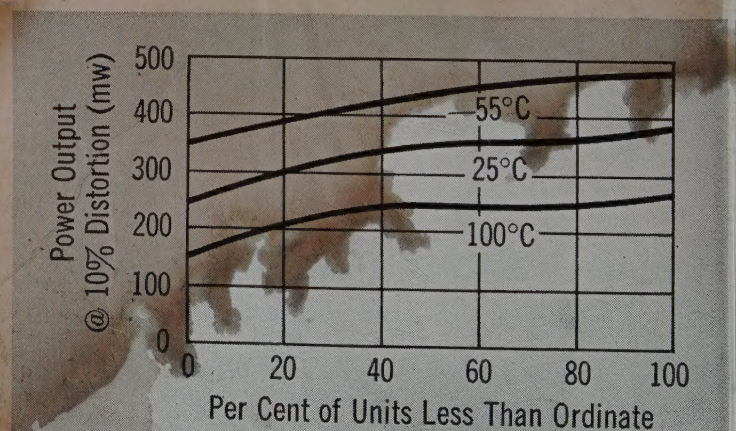
## . . . with TI 2N342A silicon transistors from stock

You can satisfy the 71°C equipment requirements of MIL-E-5272B at 100°C with the intercom amplifier circuit shown above — using TI 2N342A silicon transistors with . . . guaranteed 3-to-1 linear beta characteristics . . . 85-v collector-to-emitter breakdown, giving a wide safety range with 28-v aircraft supplies . . . plus dissipation capability of 1 watt at 25°C and 200 mw at 125°C.

The newest addition to the *use-proved* TI 2N339 series introduced in 1957, this medium-power unit carries the full-year TI guarantee and is immediately available *off-the-shelf* from all TI distributors in 1-249 quantities. For production quantities, contact your nearest TI sales office.

TYPICAL INTERCOM AMPLIFIER PERFORMANCE CHARACTERISTICS USING 2N342A TRANSISTORS

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*NOTE: Doped single crystals in other diameters, resistivities, or lifetimes not listed above can be furnished as specials.*

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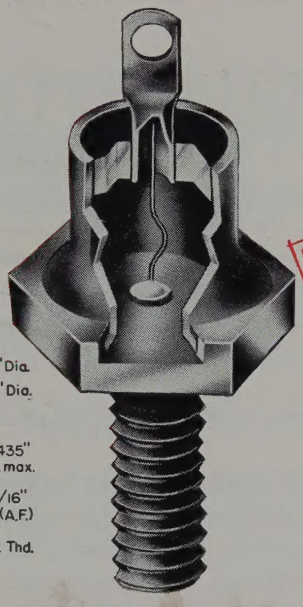

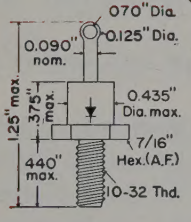


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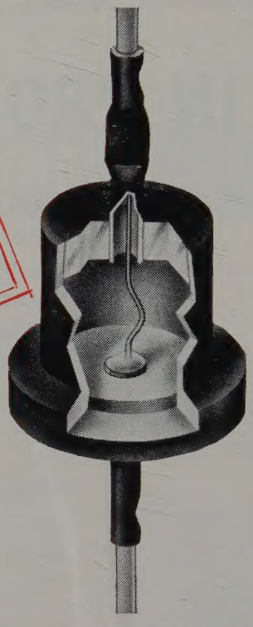
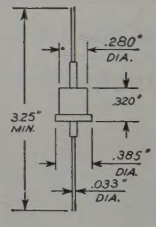
### WIRE-IN-TYPE






| TYPE | Peak Operating Voltage −65°C to + 165°C | Ave. Rectified Current 25°C | Ave. Rectified Current 150°C | Reverse Current (Max.) at Specified PIV, 25°C |
|---|---|---|---|---|
| | Volts | Amps. | Amps. | μA |
| **1N253** | 95* | 3.0 | 1.0* | 10 |
| **1N254** | 190* | 1.5 | 0.4* | 10 |
| **1N255** | 380* | 1.5 | 0.4* | 10 |
| **1N256** | 570* | 0.95 | 0.2* | 20 |
| **CK846** | 100 | 3.5 | 1.0 | 2 |
| **CK847** | 200 | 3.5 | 1.0 | 2 |
| **CK848** | 300 | 3.5 | 1.0 | 2 |
| **CK849** | 400 | 3.5 | 1.0 | 2 |
| **CK850** | 500 | 3.5 | 1.0 | 2 |
| **CK851** | 600 | 3.5 | 1.0 | 2 |

1N253 through 1N256 available to MIL specifications. *to +135°C

| TYPE | Peak Operating Voltage −65°C to +165°C | Ave. Rectified Current 25°C | Ave. Rectified Current 150°C | Reverse Current (Max.) at Specified PIV, 150°C |
|---|---|---|---|---|
| | Volts | mA | mA | mA |
| **1N536** | 50 | 750 | 250 | 0.40 |
| **1N537** | 100 | 750 | 250 | 0.40 |
| **1N538** | 200 | 750 | 250 | 0.30 |
| **1N539** | 300 | 750 | 250 | 0.30 |
| **1N540** | 400 | 750 | 250 | 0.30 |
| **1N1095** | 500 | 750 | 250 | 0.30 |
| **1N547†** | 600 | 750 | 250 | 0.35 |

1N538, 1N540, 1N547 available to MIL specifications. †Same as 1N1096

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**Front Cover**

Shown is a microphotograph of the area in the vicinity of an arsenic diffused *p-n* junction. On the electrolytically etched surface the bright lines at the junction are due to sharp doping impurity gradients. With an inversion layer present on the *p*-type region, barium titanate particles, which tend to deposit where there is a potential gradient along the surface, are seen to be spread out away from the junction. See "Some Effects of Semiconductor Surfaces on Device Operation" by G. A. deMars, page 24. Photo courtesy Raytheon Manufacturing Company.

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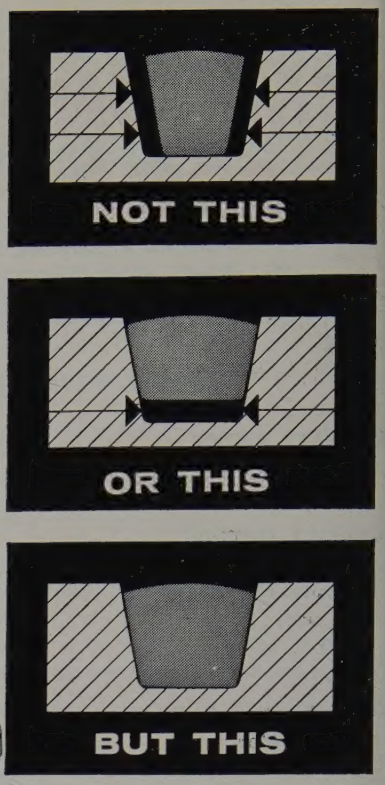
# *Precision-formed Sylvania ingots yield more single-crystal Germanium...*



Sylvania ingots are made to fit your boat exactly for maximum yield of monocrystalline germanium in horizontal crystal growing. Poorly formed ingots result in uneven melting, increased shrinkage and greater polycrystalline formation

SEMICONDUCTOR device manufacturers can rely on a greater yield of monocrystalline germanium when they specify Sylvania ingots. The size and shape of Sylvania ingots are held to tolerances within 0.005 inch on base and radius dimensions, 0.1 inch on height, and ½ degree on taper. As a result a Sylvania ingot will fit your horizontal crystal growing boat precisely, and deter polycrystalline formation. Melting is even, surface drop is held to a minimum and shrinkage is reduced. You get a greater yield of doped single crystals and lower unit costs.

Sylvania germanium ingots are available in any one of seven standard cross sections or in designs made to your specifications. Whatever form you specify, you can count on a maximum yield from Sylvania germanium ingots. Contact your Sylvania representative for further information on precision-formed germanium or write the Chemical and Metallurgical Division directly.

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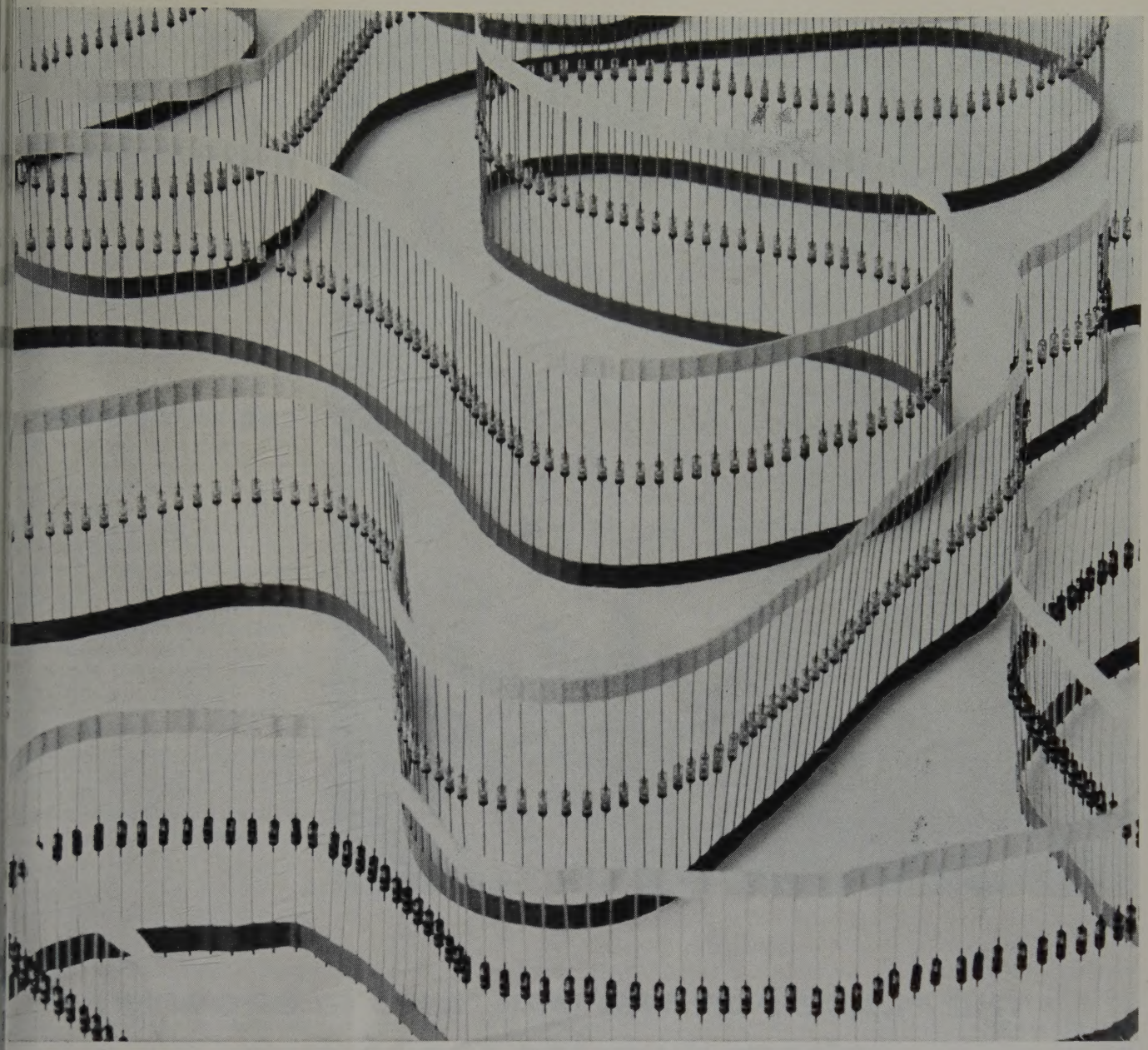

# ZENER DIODES IN A PROVEN GLASS PACKAGE

Now you can get high-performance voltage-regulator diodes in the famous, hermetically-sealed Hughes glass envelope. These diodes have an outstanding characteristic: sharp regulation of reverse voltage. This means that you can use them—with confidence—in clipping, clamping, coupling, and compensation circuits to obtain *dependable voltage regulation*. In addition, they retain this stability, together with low dynamic resistance, throughout a wide range of operating temperatures.

CHARACTERISTICS

Nominal Voltage: 2 volts to 30 volts

Power Dissipation: 250 milliwatts

Maximum Dynamic Resistance: 10 to 75 ohms

Operating Temperature Range: —65° to 175° C.

Dimensions, Diode Glass Body: Maximum Length: 0.265″ max.
Maximum Diameter: 0.105″ max.

*To obtain your copy of specifications covering the family of more than a dozen types of Hughes Silicon Voltage-Regulator Diodes, please write: Hughes Products, Semiconductor Division, Marketing Department, P.O. Box 278, Newport Beach, California.*

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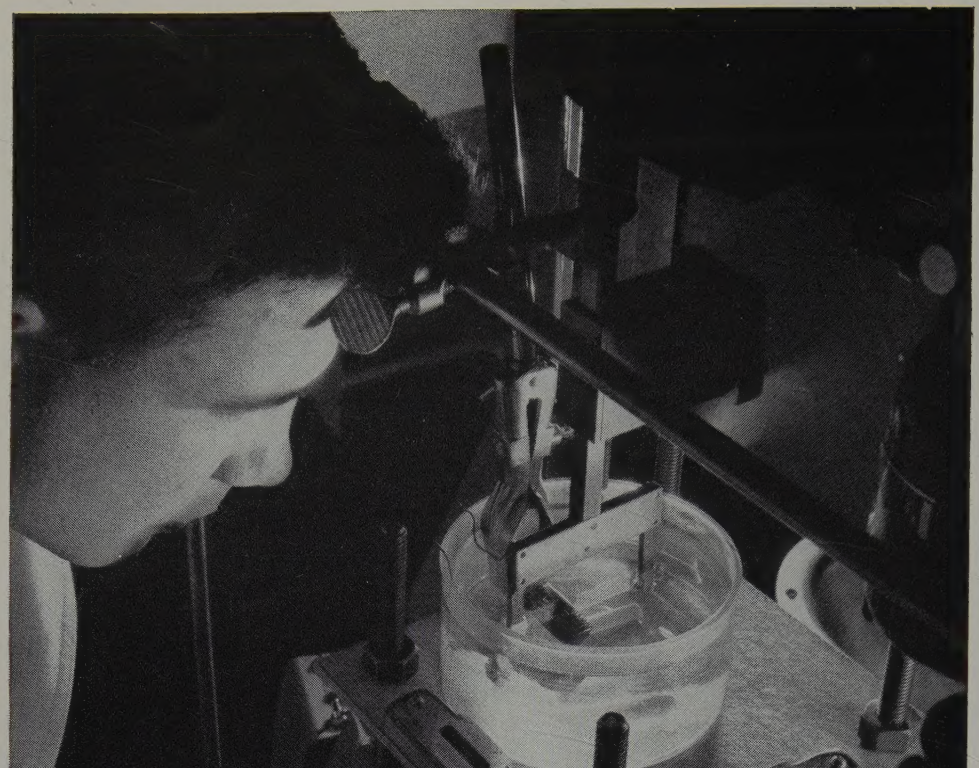


*News from Raytheon's Semiconductor Division...*

**ELECTROLYTIC SLICING**—This engineer is slicing a germanium crystal by electrolytic means. Up to now semiconductor wafers have been formed by mechanical processes, such as cutting with diamond saws or lapping with abrasive powders. The resulting mechanical damage to the critical surfaces reduces the quality and effectiveness of finished semiconductor devices. Electrolytic slicing of crystals, producing surfaces which are free from the mechanical damage resulting from other methods, is one of the many pioneering activities initiated and carried forward by the scientists and engineers of Raytheon's Semiconductor Division.

## THE PLACE FOR THE MAN WHO IS GROWING FASTER THAN HIS ASSOCIATES

There are openings at Raytheon's Semiconductor Division for scientists and engineers with semiconductor experience and a desire to find more room for personal and career growth. Opportunities exist in the following areas:

**Device Design and Development**
**Material Development**
**Mechanization**
**Circuit Design**
**Application Engineering**

You are invited to explore the advantages for yourself in associating with Raytheon's Semiconductor Division. Write to Mr. Allen S. Moorhead, RAYTHEON MANUFACTURING COMPANY, Semiconductor Division, 150 California Street, Newton 58, Massachusetts.

*The place for the man who is growing faster...*

**SEMICONDUCTOR DIVISION of RAYTHEON**

*Excellence in Electronics*

# *Editorial . . .*

### The Thermoelectric Effects

The advent of semiconductors has reawakened interest in thermoelectric effects. Although known for more than one hundred years, these have had very little application because of their small magnitude in metals.

The effects arise from dependence of the Fermi Level upon temperature and from thermodynamic properties of the free electron carriers when placed in a temperature gradient. Basically an *emf* (Seebeck effect) is generated in a conductor of semiconductor medium with a non-zero temperature gradient. This effect may actually be used to convert heat into electric power and may be enhanced by using non-homogeneous media such as dissimilar conductors or semiconductors connected with their junctions at different temperatures. The conversion efficiency is extremely small in metals, but may approach 10% in the case of semiconductors. Such efficiency is proportional to the temperature gradient, to the ratio of thermoelectric power coefficient to the electrical resistivity, and to the thermal resistivity. Maximization of the conversion efficiency is not easy, because the thermoelectric power coefficient and the electrical resistivity tend to vary in the same direction, and similarly, increases of the thermal resistivity generally correspond to increases of the electrical resistivity. Present results indicate that maximum efficiencies are obtained using very highly doped semiconductors. Of interest also, is the fact that the Seebeck *emf* is of opposite sign for *p*-type and *n*-type semiconductors.

The inverse of the Seebeck effect (Peltier effect) is obtained when electric power is supplied to a thermoelectric circuit. As a result a temperature gradient is produced, and the corresponding cooling effect may reach 90°C below the temperature of the hot junction.

Foreseen and partly realized applications of thermoelectric effects are power generators, refrigerators, special devices for the measurement of temperature, current, electric power, etc. As power generators, the thermoelectric units compete well with solar cells, batteries, etc., especially if used in conjunction with nuclear heat sources. As refrigerators, they are advantageous in special circumstances, where small size or inconvenient locations present special problems. A wide open field for applications of the thermoelectric effects is in the field of measurements. We predict that thermoelectricity will shortly play an important and substantial role in our economy.

### Transistorized Equipment May Reduce Highway Accidents

A new proximity warning device is being tested by General Motors. Employing a transistorized transmitter and receiver, and using radar principles, it warns a driver when he is approaching an object in front of him at a dangerous rate of speed. Such a device might be valuable in preventing highway accidents caused by drivers who are unaware of their danger. Devices, such as these, that contribute to safety on the highways are worthy of the fullest support of everyone.

### Reprints of Articles

As a service to our readers we are making available single reprints of any article appearing in SEMICONDUCTOR PRODUCTS if a request for such a reprint is forwarded to us on company letterhead. Inasmuch as a limited number of reprints are published, it is suggested that requests be forwarded as soon as possible.

### An Unusual Brochure

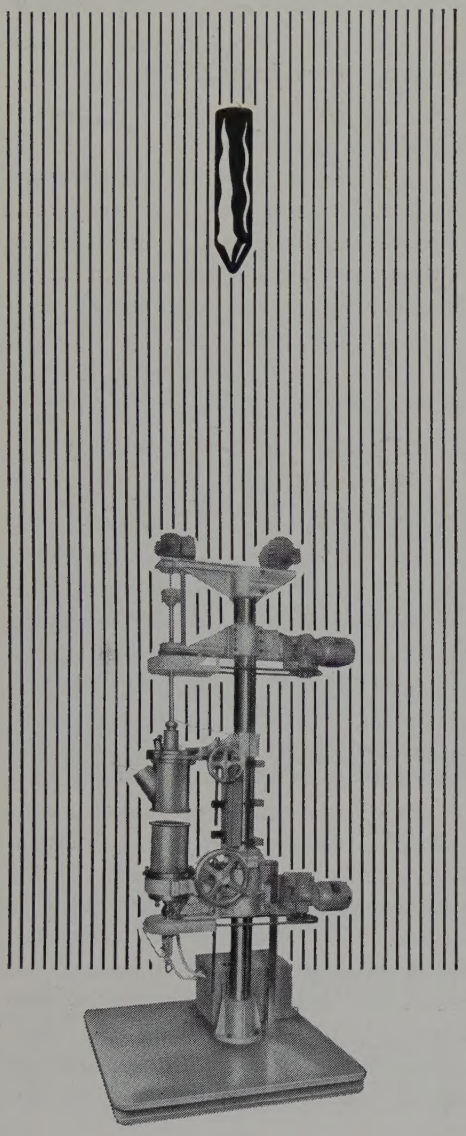
Occasionally a device manufacturer makes available a brochure which is at once interesting, instructive and intriguing. Rarely is it indispensable. In our opinion all of these accolades may be used to describe the brochure entitled, "Varactors" prepared by Dr. Arthur Uhlir, Jr., of Microwave Associates, Inc. We strongly recommend that engineers engaged in electronic design obtain this booklet. Written in a clear vein, it describes the theory, characteristics, and the many applications of these semiconductor diode capacitors.

### Omission

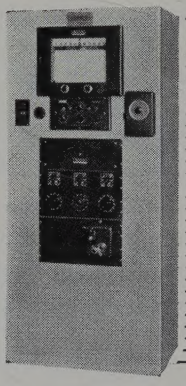
The following corrected statement concerning the present affiliation of A. W. Carlson, author of the article entitled "Transistor Switching Circuits" (Part I, January 1959; Part II, February 1959) was inadvertently omitted in the byline: "This article is part of a project undertaken by Mr. Carlson for CBS-Hytron, while a member of its semiconductor applications engineering department, to produce a series of articles covering transistor parameters and circuitry and has been released by CBS-Hytron for publication in SEMICONDUCTOR PRODUCTS. Mr. Carlson is presently Director of Research for Transistor Applications, Inc."

*Samuel L. Marshall*

# THE BEST SEMI-CONDUCTORS MADE....



# ARE MADE ON KĀHLE MACHINES



*KAHLE CRYSTAL GROWING MACHINES . . . featuring a single unit for temperature, timing, programming, and motor control...set new high-precision standards in the production of single billets of Germanium, Silicon, or related semiconductor crystals. Designed to function efficiently and economically with either RF or resistance-type heating systems, each machine is pre-tested . . . under actual operating conditions . . . prior to shipment.*

*This machine is just one example of the full line of fine Kahle equipment for the production of semiconductors and electron tubes.*

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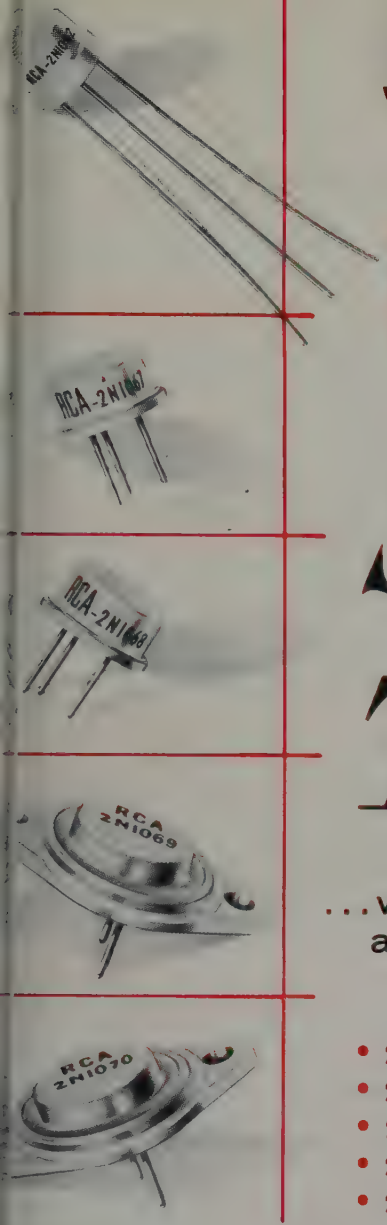
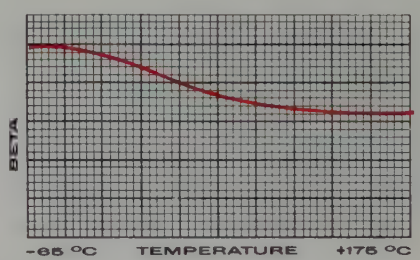
# 5 new RCA Silicon Transistors

DIFFUSED-JUNCTION MESA




...with excellent beta stability from −65°C to +175°C and exceptionally low saturation resistance!

- 2N1092—medium power
- 2N1067—intermediate power
- 2N1068—intermediate power
- 2N1069—high power
- 2N1070—high power




CA's new n-p-n silicon transistors offer significant reduc- ns in saturation resistance, and feature excellent beta stabil- over the entire operating temperature range. These features sult from use of RCA's advanced diffused-junction mesa chnique. These transistors are designed to meet stringent litary environmental, mechanical, and life test requirements. RCA silicon transistors offer the equipment designer a wide oice of power-switching capability in preferred industry cases (JEDEC TO-3, TO-8, and TO-5).

RCA SILICON TRANSISTORS are commercially available in limited quantities. Your RCA Field Representative has complete information on these units and will be glad to discuss with you other silicon transistors now under development. For technical data on the 2N1092, 2N1067, 2N1068, 2N1069, and 2N1070, write RCA Commercial Engineering, Section D-100-NN, Somerville, N. J.

| | | ABSOLUTE-MAXIMUM RATINGS | | | | CHARACTERISTICS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | At Case Temperature of 25°C | | | | | | At Case Temperature of 175°C | | |
| | | | | | | Saturation Resistance (ohms) | | | DC Current Gain (Beta) | | | DC Collector Cutoff Current ($I_{CBO}$) (μa) | | |
| ype | JEDEC Outline | $V_{CES}$● (volts) | $V_{CEO}$▲ (volts) | Collector (amp.) | Transistor Dissip. # (watts) | Typical | Max. | Conditions | Typical | Min. | Conditions | Typical | Max. | Conditions |
| 1092 | TO-5 | 60 | 30 | 0.5 | 1 | 3 | 10 | $I_C$=200 ma. | 20 | 10 | $I_C$=200 ma | 75 | 1000 | $V_{CBO}$=30 volts |
| 1067 | TO-8■ | 60 | 30 | 0.5 | 2.5 | 3 | 10 | $I_C$=200 ma. | 35 | 15 | $I_C$=200 ma | 75 | 1000 | $V_{CBO}$=30 volts |
| 1068 | TO-8■ | 60 | 30 | 1.5 | 5 | 1 | 2.67 | $I_C$=750 ma. | 38 | 15 | $I_C$=750 ma | 75 | 1000 | $V_{CBO}$=30 volts |
| 1069 | TO-3 | 60 | 45 | 4 | 25 | 0.7 | 2 | $I_C$=1.5 amp. | 20 | 10 | $I_C$=1.5 amp | 150 | 2000 | $V_{CBO}$=30 volts |
| 1070 | TO-3 | 60 | 45 | 4 | 25 | 0.4 | 0.67 | $I_C$=1.5 amp. | 20 | 10 | $I_C$=1.5 amp | 150 | 2000 | $V_{CBO}$=30 volts |

■"Heat-Sink" mounting clamp supplied.
●Collector-to-emitter breakdown voltage with base connected to emitter
▲Collector-to-emitter breakdown voltage with base open
#At a case temperature of 100°C

**RADIO CORPORATION OF AMERICA**
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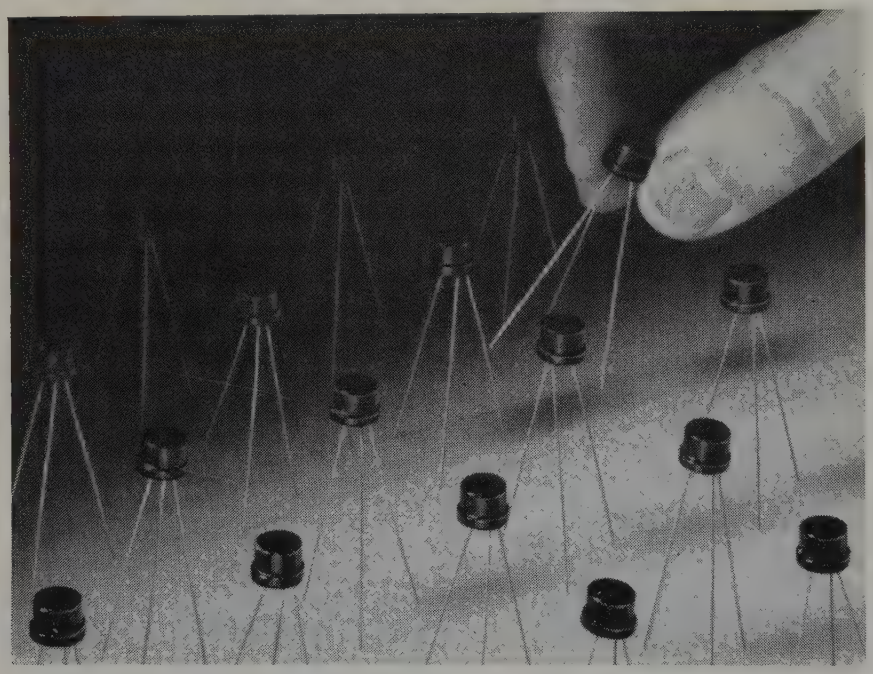

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# PERSONNEL NOTES

Charles W. Martel has been named Advertising and Sales Promotion Manager for the Semiconductor Division of Raytheon Manufacturing Company. In announcing the appointment, Harvey Finison, division manager, said that Mr. Martel, whose office will be at 215 First Avenue, Needham Heights, Mass., would direct national advertising and sales promotion activities for Raytheon transistors, and semiconductor diodes and rectifiers. Mr. Martel was graduated from M.I.T. in 1931 with a degree in physics. He is a senior member of the Institute of Radio Engineers, a member of the American Institute of Electrical Engineers, and a Lt. Colonel in the Air Force Reserve.

Dr. Adolph Goetzberger, formerly semiconductor physicist with Siemens & Halske, Munich, Germany has been named senior physicist for the Shockley Transistor Corporation. Announcement of the appointment was made by Dr. William Shockley, president of this subsidiary of Beckman Instruments, Inc. In his new post, Dr. Goetzberger will be concerned with the development of improved forms of semiconductor devices.

Young Kim has returned to Allen B. Du Mont Laboratories to head the photoemissive and solid-state devices section. Formerly a senior research engineer in the pioneer electronic firm's advanced development laboratory, Mr. Kim acted as consultant and helped develop Du Mont equipment for the Office of Naval Research's Army-Navy Instrumentation Program. Since joining Du Mont in 1956, he has been involved in flat display device projects, infra-red guidance and tracking systems, computer programming, and satellite vehicle reconnaissance.

Mallory-Sharon Metals Corporation, Niles, Ohio, has named three engineering and product specialists to its process engineering group. They will assist Mallory-Sharon customers relative to extrusion, rolling, and tubular problems related to their use of special metals. Earl L. Richards, named a senior process engineer, has extensive experience in the field of zirconium technology and fabrication. Scotto N. Randall's work will be devoted primarily to the development of special metals tubing. Roy E. Rohrabaugh, an extrusion specialist, will be working on development of special metals extrusion.

Transitron Electronic Sales Corporation, Wakefield, Massachusetts, has opened a sales office in St. Paul. The office at 1821 University Avenue, will be managed by Mr. William F. Harrison. Mr. Harrison was formerly with Remington-Rand and has wide experience in the field of electronics. The opening of this new branch Transitron officials state, reflects increased sales activity and further expansion in the Mid-Western market.

Four assistant managers have been named in the Research division of Ray-

theon. Hugh R. Boyd, technical assistant to the division manager and acting administrative manager for the past five years, will be responsible for administration. Dr. Luther Davis, Jr., manager of the Solid State Physics group for the past six years, will be responsible for planning and coordinating the current program. Dr. Walter F. Leverton, manager of the Physical Electronics group for the past six years, will be responsible for transferring research results into operating division products. Dr. Hermann Statz, manager of the Theoretical Physics group for the past six years, will be responsible for keeping abreast of world-wide scientific developments and trends and recommending new projects when indicated.

Elby D. Martin and Harry L. Anderson have been named Military Relations Engineers for Semiconductor-Components division of Texas Instruments. From headquarters in TI's new Western Region office at 9033 Wilshire Blvd., Beverly Hills, Calif., Mr. Martin will provide engineering assistance to military procurement agencies in the western states. Mr. Anderson will provide engineering service to military agencies in the Huntsville-Tullahoma area from his office in the Hutchens Building, Huntsville, Alabama.

William H. Hall has been named manager of marketing for General Electric's newly organized rectifier components product section of the Semiconductor Products Department. Mr. Hall's office will be at the section's headquarters in Syracuse, N. Y. Mr. Hall will direct and be responsible for all marketing activities of General Electric's component rectifier business.

Charles A. Moore has been named engineering field representative and applications engineer on the sales staff of F. W. Sickles Division of General Instrument Corporaiton located at Chicopee, Mass. An engineering graduate of Tri-State College, Angola, Indiana, Mr. Moore served in the Air Force from 1944-1946 during which time he was assigned to special electronics research projects.

The appointment of Arthur L. Wannlund, Jr. as Director of Device Engineering was announced by Dr. D. M. Van Winkle, Vice President and Technical Director of Continental Device Corporation. Mr. Wannlund was formerly head of device research in the Semiconductor Division of Hughes Aircraft Company where his most recent work was concerned with the development and instrumentation of new silicon transistor.

Transitron Electronic Sales Corporation of Wakefield, Mass., broadened their West Coast activity with the opening of a sales office in Hollywood. The office at 6362 Hollywood Blvd., will make available the services of field engineers William B. Cornelius, Robert J. Bertrand, Richard L. Larson, and Robert A. Styles. All have excellent experience in the field of semiconductors.

Philco Corporations' Lansdale Tube Company division has announced key appointments to handle its expanding transistor operations. John M. Palmer has been named manager of semiconductor operations; Otto G. Honzl, manager of quality control; Stuart L. Parsons, director of equipment development; Clarence G. Thornton, director of semi-conductor development; and Robert F. Lake, manager of industrial engineering.


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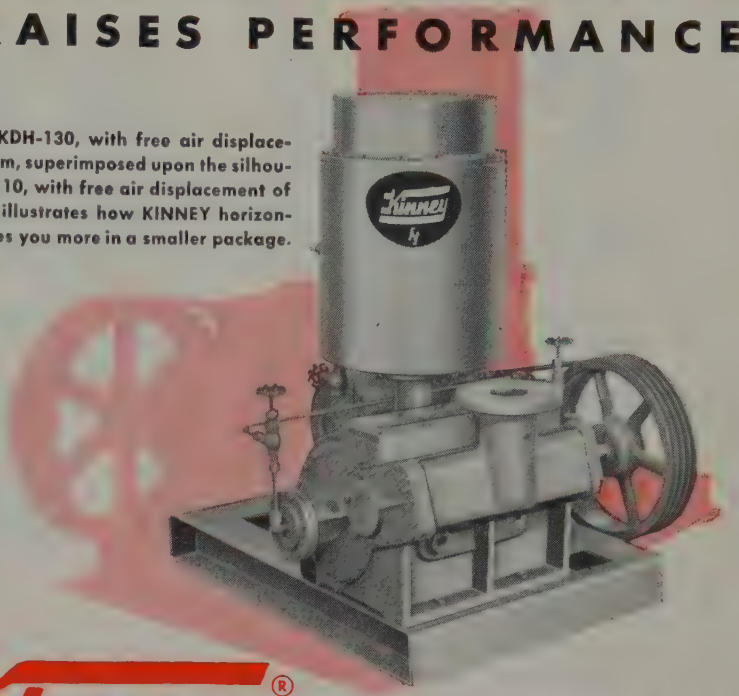

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| KDH-130 | 3' 4⅝" | 131 | 5 | 840# |
| KDH-150 new | 3' 4⅝" | 150 | 7½ | 1055# |
| KDH-220 | 4' 10¾" | 218 | 10 | 2100# |
| KD-310 | 6' 3" | 311 | 15 | 3400# |
| KD-485 | 6' 7" | 486 | 25 | 5300# |
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| KD-780 | 6' 7⅜" | 780 | 40 | 6700# |

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Stanley F. Molner has been appointed Senior Applications Engineer by Epsco-West, according to an announcement by W. E. Rianda, general manager of the Anaheim, California electronic systems and data handling firm. Mr. Molner will specialize in applications engineering of special purpose digital computers, airborne pulse code modulation systems, all types of ground telemetering stations, and large scale missile and aircraft checkout systems in the new post.

The W. L. Maxson Corporation announces the appointment of Mr. S. Paul Shackleton as Staff Scientist in the Research and Development Division. Mr. Shackleton as Staff Scientist in the Redesign planning of radar and communications systems. Mr. Shackleton was, for forty-one years, in the Bell System, first in Engineering and then in Development and Research with the American Telephone and Telegraph Company.

Thomas H. Morrin, director of engineering research at Stanford Research Institute, announced two organizational changes. A new unit, the communications and propagation laboratory, has been established with Dr. Allen M. Peterson as manager, and Dr. F. J. Kamphoefner has been appointed manager of the control systems laboratory. A specialist in industrial instrumentation and control problems, Dr. Kamphoefner has been with SRI since 1949. Concurrent with his SRI duties, Dr. Peterson is a member of the Stanford University faculty.

The appointment of Dr. Marvin G. Britton as development manager of the New Products Division of Corning Glass Works was announced by Division Manager Forrest E. Behm. Dr. Britton has been with the company for nine years, working primarily in the field of refractory development. He has most recently been with the Ceramic Research Dept. as a senior research associate.

Appointment of Paul Mariotti as applications engineer is announced by H. A. Finke, general manager of Polytechnic Research and Development Co., Inc., Brooklyn, New York. For the past 16 years, Mr. Mariotti headed the Electromechanical Design Group on Microwave Test Equipment at the Microwave Research Institute of the Polytechnic Institute of Brooklyn.

Thomas D. Hinkelman has been appointed Manager of Product Planning and Market Research, according to an announcement from R. H. Rudolph, Manager of Marketing for the Motorola Semiconductor Products Division. In his new capacity, Mr. Hinkelman will be responsible for planning future transistor products of the company, and the technical competitiveness of current products.

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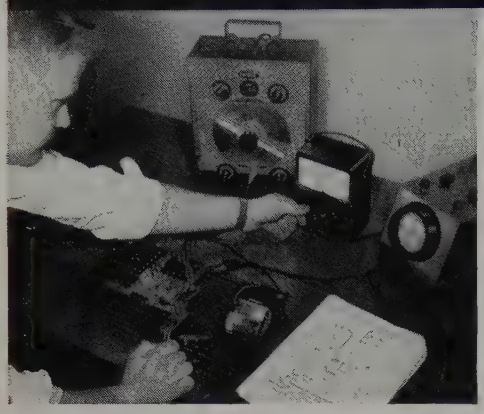

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# Industry News

A new firm, Allegheny Electronic Chemicals Co., has been formed for the production of silicon in all forms for the semiconductor industry, according to a joint announcement by Norman J. Egli, manager of sales and Thayer Rudd, plant manager, for the firm. Production has started at the firm's Bradford, Pennsylvania plant, and deliveries to customers are currently being made. Silicon will be available in a wide variety of forms including needles, densified chunks, densified rods, single crystals (both Czochralski and float zoned), rough cut and lapped single crystal slices, seeds and master doping alloys. A subsidiary of The Baugh Chemical Company and Baugh and Sons Company, Baltimore, Maryland, the firm maintains its production facilities at Lewis Run near Bradford, Pennsylvania. The forty acre plant site was chosen because of the area's high degree of air purity which is helpful to the production of high-grade clean electronic chemicals. Air used in the production and laboratory buildings, however, is completely purified as it is drawn in from outside. The bulk polycrystalline silicon produced by the chemical portion of the plant is of exceptional uniformity, in the range of 100 to 300 ohm-centimeter resistivity.

A Solid State Materials Laboratory has been organized as part of the recently established Solid State Electronics Department at Motorola's Phoenix, Arizona location. Staffed with recognized experts in the field, and directed by D. L. Fresh, this laboratory provides an immediate capability for research, development and manufacture of Solid State Ceramic Materials. Already equipped with the most modern instrumentation, the laboratory currently occupies approximately 4,500 square feet in the Motorola Research building. This space can be increased as the need arises.

Bradley Semiconductor Corporation has moved into new headquarters, merging under one roof the production operations which were formerly divided between two separate plants in downtown New Haven, Conn. The general Bradley line of selenium and copper oxide rectifiers, modulators and arc suppressors has for a number of years been manufactured at the company's former main building, while the newly-introduced "Redtop" silicon diode has been coming from a nearby subsidiary plant. The new building has been designed to the company's specific needs, and comprises 30,000 square feet on one level, ample for the company's present 160 production personnel.

Because of the response to the first High Temperature Symposium held in Berkeley, California, three years ago, Stanford Research Institute, Menlo Park, Cal., is sponsoring a second meeting October 6-9, 1959. Since 1956 there has been a series of significant technical developments in fields depending on high temperatures. The 1959 symposium will be expanded to include representatives from abroad who will describe recent important developments in high-temperature technology in their countries.

1958 was the most successful year in the history of Texas Instruments Incorporated with sales 37% higher and earnings after taxes 60% greater than in 1957, the best previous year, Chairman of the Board J. E. Jonsson and President P. E. Haggerty state in the company's annual report mailed to stockholders. TI's new 310,000 sq ft Semiconductor-Components division plant was completed and brought into production early in the year and a 192,000 addition to the structure was started early in 1959. Construction of an 87,000 sq ft building to house the Central Research Laboratory was started in 1958 and is scheduled for completion at mid-year 1959. Both buildings are located on TI's 300-acre site in North Dallas. Also during 1959, construction is due to get under way on an additional plant of more than 100,000 sq ft for Texas Instruments Limited at Bedford, England, with occupancy scheduled for 1960.

Dr. Mervin J. Kelly, chairman of the board of directors of Bell Telephone Laboratories, retired on March 1, after 41 years of scientific and administrative service with the Bell Telephone System. One of the nation's leaders in the field of industrial research, Dr. Kelly began his Bell System career in 1918 as a research physicist with the research division of the Western Electric Company's engineering department. This department was later incorporated as Bell Telephone Laboratories. To honor Dr. Kelly on the occasion of his retirement the American Institute of Electrical Engineers and Bell Telephone Laboratories have announced the establishment of an annual award for achievement in the field of telecommunications, to be known as the Mervin J. Kelly Award. The first Award will be made in 1960. It will consist of a bronze medal, a cash stipend of $1,000, and a certificate.

A significant advancement in improved communication systems for man-made satellites has been achieved in the Philco research laboratories. In a paper presented at a two-day Solid-State Circuits Conference held at the University of Pennsylvania, Mario Fortini of the Philco Solid-State Electronics staff and Juri Vilms also of Philco and Drexel Institute of Technology revealed that an all-semiconductor (tubeless) 2000-megacycle source of microwave power is now a reality. This source of microwave power would enable future U.S. satellites to transmit in the desirable 1000-2000 megacycle range without increasing weight or size requirements.

A call for papers for the Fifteenth Annual National Electronics Conference has been issued by M. E. Van Valkenburg, NEC program chairman. The NEC, scheduled for October 12 through 14, 1959 at the Hotel Sherman, Chicago, will consider papers reporting research and development results not previously published in the following fields: adaptive servomechanisms, antennas and propagation, audio, circuit theory, communication systems, computers, information theory, instrumentation and telemetry, masers, microminiaturization, microwaves, millimeter waves, parametric amplifiers, plasma research, radar and radio navigation, servomechanisms, signal matched filters, solid-state circuits, solid-state devices and materials, space electronics, communication and navigation, television, transistors and value engineering. Abstracts, no longer than 200 words, must be received by May 1. They should include title, author, and author affiliation. Ten copies of the abstract should be sent to M. E. Van Valkenburg, Electrical Engineering Department, University of Illinois, Urbana, Illinois. Completed manuscripts of accepted papers will be required by September 8, 1959.

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# An Analysis of Impurity Distributions and Their Relation to Electrical Behavior of Conventional Transistor Constructions

DRS. PETER KAUFMANN* and GEORGE FREEDMAN**

PART 1

**This article attempts to relate the electrical performance of transistors to the bulk impurity variations inherent in their construction. An "ideal" or "most versatile" impurity distribution is hypothesized which satisfies most transistor applications. Ten real distributions of the most common types are calculated and are related to the ideal one. All distributions of impurities are shown to be consistent with the metallurgical phenomena (diffusion and alloy segregation) which must necessarily produce them. These impurity distributions are derived directly from the mathematical relations which describe the metallurgical phenomena.**

ONE OF THE MAJOR problems in transistor manufacture is that of producing devices consistently within specified narrow spreads of electrical performance. Tight limits on performance quality can be achieved only by careful design of the device on both the gross and atomic levels and by careful monitoring of the manufacturing processes. These include the now familiar procedures of wafer-making, etching, lead attachment, surface treatment, junction formation, packaging, etc. Perhaps the most important single variable, however, is that of producing a desired impurity distribution in single-crystal chips of semiconductor material.

Impurity gradients in transistors exist as a result of metallurgical phenomena. These gradients are either deliberately employed by transistor designers and fabricators to achieve desired electrical performance, or they are tolerated and compromises are made as unavoidable accompaniments of the manufacturing processes. In any case, impurity distribution variation is largely responsible for spreads in electrical performance encountered in transistor manufacture on the one hand, and the preference of the user for type "A" over type "B," on the other.

This article will attempt to analyze the reasons for differences in transistor performance, as they exist in presently available units, as a function of impurity distribution factors. All other design features such as base rings, extent of junction area, etc. will be considered outside of its scope. The article will confine itself to the most common transistor types, such as germanium or silicon *n-p-n* or *p-n-p* devices.

*Formerly Group Leader, Physics Group, Advanced Development Laboratory, Semiconductor Division, Raytheon Mfg. Co. Now at Swiss Federal Institute of Technology, Dept. of Advanced Electronics, Zurich, Switzerland.

**Chief Development Engineer, Advanced Development Laboratory, Semiconductor Division, Raytheon Mfg. Co.

## Design Concepts

The logical starting point in transistor design is the end use of the device. Transistors may be qualitatively classified with respect to purpose as follows:

1. Power
   (a) low
   (b) medium
   (c) high
2. Frequency
   (a) low
   (b) medium
   (c) high
3. Circuit
   (a) video and audio amplifiers
   (b) tuned amplifiers and oscillators
   (c) switches

The 27 combinations which follow from this classification cover most of the uses of transistors either actual or contemplated at this time (these combinations are made from the three different main categories, for example, "low-power, low-frequency audio amplifiers").

While each circuit may demand its own variations in transistor construction, it must be pointed out that not all of these are necessarily dependent on differences in impurity distribution in the semiconductor. Thus, in a one-dimensional unit-element encompassing emitter, base, and collector (as shown in *Figs. 2-12*), the ideal impurity distributions for a high-power audio amplifier and a low-power video amplifier could well be identical. Differences in other features, however, might be considerable, e.g., size, package, contacts, geometry, etc. Indeed, for a majority of circuit purposes, experimentation with a large number of different impurity distributions would not be necessary if only a *single "ideal" distribution could be attained* which satisfies a great variety of requirements.

TRANSISTOR PERFORMANCE PARAMETERS AS FUNCTION OF IMPURITY DISTRIBUTIONS IN DIFFERENT STRUCTURAL ZONES

| ELECTRICAL PARAMETERS / THE FIVE TRANSISTOR STRUCTURAL ZONES | $\alpha_{fe}$ | $r_{b\,extr}$ | $C_c$ | $f_{\alpha_b}$ | $V_p$ | $BV_{cb}$ | $V_{sat.}$ | $V_{min}$ | FINAL GRADIENT SELECTED (see figure 1) |
|---|---|---|---|---|---|---|---|---|---|
| DESIRED PARAMETER LEVEL SUITABLE FOR ALL 27 TRANSISTOR TYPES | HIGH | LOW | LOW | HIGH | HIGH | HIGH | LOW | LOW | |
| IMPURITY CONCENTRATION LEVELS DESIRED IN EACH STRUCTURAL ZONE* | | | | | | | | | |
| EMITTER | VERY HIGH DOPING LEVEL | — | — | — | — | — | VERY HIGH DOPING LEVEL | — | |
| EMITTER TO-BASE TRANSITION ZONE | STEP JUNCTION | — | — | STEP JUNCTION | — | — | STEP JUNCTION | — | |
| BASE | LOW AT EMITTER, VERY LOW AT COLLECTOR | HIGH | LOW NEAR COLLECTOR | HIGH AT EMITTER LOW AT COLLECTOR | HIGH | LOW | LOW | — | |
| BASE-TO-COLLECTOR TRANSITION ZONE | — | — | GRADED | — | GRADED | GRADED | STEP JUNCTION | "INTRINSIC" PORTION VERY PURE OR NARROW | |
| COLLECTOR | — | — | LOW NEAR BASE | — | LOW NEAR BASE | LOW | VERY HIGH | HIGH | |

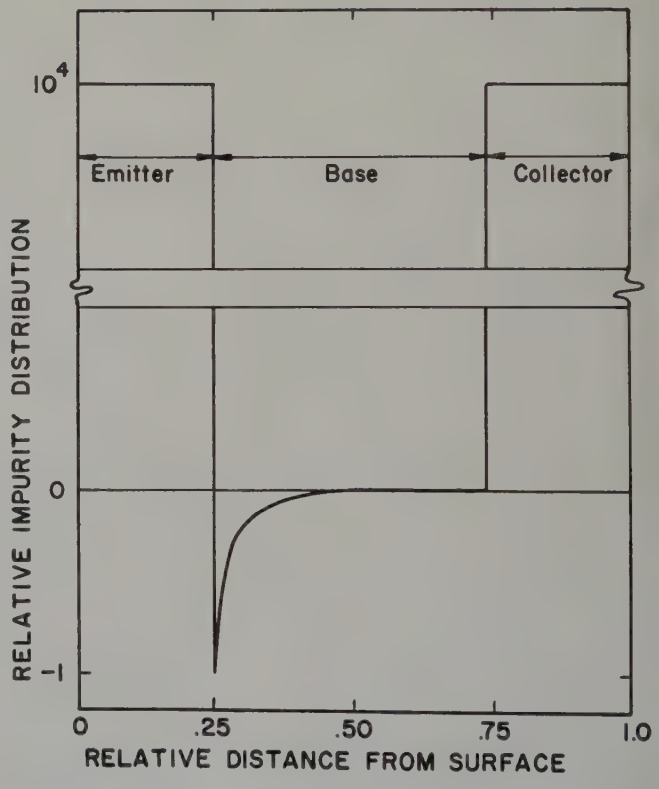
*A DASH INDICATES THAT THE IMPURITY DISTRIBUTION IS NOT IMPORTANT FOR THAT PARAMETER

TABLE I

Such a distribution in a transistor may be hypothesized (*Fig. 1*) on the basis of Table I which summarizes the qualities desirable for most of the 27 end uses mentioned, together with the dependence of these qualities upon impurity arrangements in different portions of the emitter, base and collector regions.

Table I results from well known design facts, [1] [9] [10] [35], which can be adequately considered in a qualitative manner.[1,2] Thus:

1. $\alpha_{fe}$ is high when: [16] [31] [43] [22]
   (a) emitter efficiency is high
   (b) base width is small
   (c) there is an aiding field in the base region due to an impurity gradient
2. $r_{b\,extr.}$ is low when base doping is high. [26]
3. $C_c$ is low when the base-to-collector transition zone is gradual. [11] [17]
4. $f_{ab}$ is high when: [22] [30] [36]
   (a) base-width is small
   (b) there is an aiding field in the base region due to an impurity gradient
5. $V_p$ is high if base doping is high, at least in some portion of the base, [33].
6. $BV_{CB}$ is high if base doping is low. [12] [25]
7. $V_{SAT}$ is low if: [13]
   (a) $\alpha_{fe}$ is high
   (b) $\alpha_{rb}$ is high
   (c) collector and emitter series resistances are low




The base region is graded to allow high avalanche breakdown. The emitter and collector are very heavily doped. An intrinsic region connects base and collector. The basegrading function [17] may be expressed as $N_A - N_D = C_1 x^{-1.16} + C_2$.

**Fig. 1—Ideal transistor profile.**

[1]Table I is considered significant only if the geometry and such physical parameters as lifetime, mobility, etc. are considered the same for all approaches.

[2]For meaning of symbols, see "List of Symbols."

8. $V_{min}$ (the minimum voltage required in an intrinsic region) is low if, [11] [21], the "intrinsic" region is extremely pure and thin.

The "ideal" or "most versatile" impurity arrangement (*Fig. 1*) which results from these considerations is built up section by section as indicated in bold lines in the last column of Table I. Some parts of the profile are necessarily the result of compromise, where different effects oppose each other. Here the authors have exercised their judgment as to which choice to make. It should be noted that the base gradient does not have the same shape as the commonly encountered error function complement, but rather approximates a $1/x$ variation, [17], in order to optimize $BV_{OB}$.

In the opinion of the writers, the design shown in *Fig. 1, when considered from the point of view of impurity profile alone,* meets more performance criteria than any other. It is at the same time a structure which is realizeable with known metallurgical phenomena although difficult to achieve precisely because of the unusual base grading.

The questions to be raised now are:

1. How do the impurity profiles of the available and the ideal transistors relate to known metallurgical phenomena?
2. What are the limitations or advantages of the devices which deviate from the ideal distribution?
3. How closely do the various impurity profiles used today approach this ideal impurity distribution?

### Transistor Metallurgy

Essentially, there are only two basic physical phenomena that are used for junction formation, [7] [19] [28] [41], and creation of impurity distributions. *This is because practical semiconductor devices are alloys, which are conventionally made either by the melting and freezing-in of impurities, or by the diffusion of impurities into or out of the semiconductor.*

Freezing-in is a directional process in which one region of the melt starts to solidify, and proceeds until the melt is completely frozen. In the course of this process, the amount of impurity retained in solid solution varies in accordance with the segregation principle[3]

$$N(x)_1 = k\,N_o\,(1-g)^{k-1} \qquad (1)$$

where:

$N(x)$ is the impurity density at any distance $x$,

$N_o$ is the original concentration of solute in the liquid,

$k$ represents the segregation coefficient[4] (ratio of impurity concentration in the solid to that in the liquid, [7] [8] [15], at the interface), and

$g$ is the fraction of the original volume which has solidified.

The segregation principle is used in crystal growing, zone refining, the alloying process of the fusion alloy transistor, the meltback transistor, etc.

Diffusion, [2] [20], is also a directional process, in which impurity atoms move in the direction of lower concentration. This process may occur for any combination of states of matter such as vapor, liquid, or solid into or out of the semiconductor. For one dimension the diffusion principle is described by the diffusion equation:

$$\frac{\delta N}{\delta t} = \frac{\delta}{\delta x}\left(D\,\frac{\delta N}{\delta x}\right) \qquad (2)$$

where,

$N$ = the impurity concentration at distance $x$ and time $t$.

$D$ = the diffusion coefficient (a function of temperature). [7] [8] [15]

With proper programming of temperature, impurity reservoir, etc., a great variety of impurity gradients can be achieved. However, most of the ten basic transistor constructions described in the following text make very little use of complex programming.

In the case most frequently encountered in transistor fabrication i.e. a constant impurity concentration at the diffusing interface at a single diffusion temperature, a solution of the diffusion equation is the well-known complementary error function:

$$N(x) = N_o\,erfc\left(\frac{|x|}{2\sqrt{Dt}}\right) \qquad (3)$$

where $N_o$ is the reservoir impurity concentration at the interface and $x$ is the distance from the interface. This law applies to the cases of diffusion into solid from either vapor or liquid reservoirs.

In the case of "bulk diffusion" (solid into solid), an effective[5] concentration, $N_e$, at the interface is assumed. This solution (4) of the diffusion equation then includes the loss of impurities from the reservoir.

$$N(x) = \frac{N_e}{2}\,erf\,\frac{x}{2\sqrt{Dt}} \qquad (4)$$

where $x$ is measured from the interface and the direction of lower concentration is considered positive.

### Ten Important Impurity Profiles

Impurity distributions for available transistors may

[3]This form of the law assumes that no addition of solvent or solute occurs during the solidification process. Where such addition does occur (as in the grown transistor), the proper boundary conditions must be introduced in order that the proper segregation law may be derived.

[4]The segregation coefficient depends upon the amount of solute present and upon the freezing speed. It approximates unity for all alloys if the freezing speed is faster than the solute diffusion rate in the liquid state.

[5]The effective concentration is assumed to be the average of the reservoir concentration and the concentration of the semiconductor prior to diffusion.

be described by using basic equations (1) and (2). These distributions are built up by applying suitable solutions of the pertinent equations to each processing step in the device fabrication. Where necessary, interactions of effects are considered. Mathematical representations of the process steps are given in the legends for these figures. Impurity profiles (*Figs. 2* through *12*) for actual emitter-base-collector elements are presented in patterns as nearly similar as possible in order that meaningful conceptual comparisons may be made. All distributions are given in three parts—the donor impurities ($N_D$), acceptor impurities ($N_A$), and the resultant of donors and acceptors. Linear scales are used whenever possible since the distribution differences show most realistically when this is done.

A typical mechanical construction illustration is presented with each profile in order to locate, within the "real" transistor, the one-dimensional element described. Liberties are taken with scales throughout in order to confine all information to a single illustration for each case. An important consideration here is that all curves and sketches are quantitive as calculated from the two metallurgical relations, and points picked from the curves have real meaning for actual transistor structures, if suitable allowance is made for second-order manufacturing effects and non-equilibrium conditions. In general, these effects seem to have only small influence since the electrical performance of most transistors is as predicted from these impurity distributions.

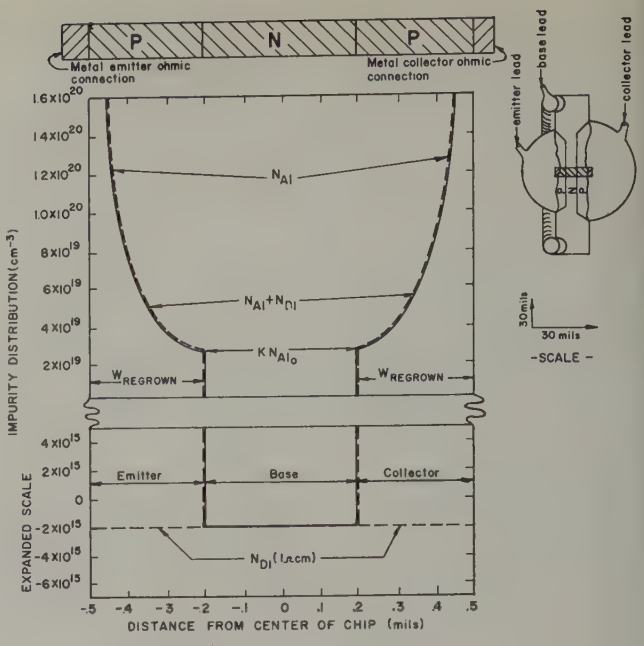
Actual transistors (germanium or silicon of either *n-p-n* or *p-n-p* types) are presented in the profiles. As far as can be ascertained, the impurities indicated as doping materials are the ones in actual use. This is important since diffusion constants and segregation factors vary greatly for each impurity-semiconductor combination. The constants, formulas, assumptions, etc. on which the profile calculations are based are indicated in the legends accompanying each figure. The potential electrical performance for each profile is summarized in Table II at the conclusion of part 2.

The constructions to be discussed may be classified by those manufacturing techniques which make use of the two metallurgical principles.

Only the distinctive metallurgical and electrical features of the different devices will be discussed in the following paragraphs.

*A. Fusion-alloy* [23] [38]

This transistor, using only the segregation principle, is shown in *Fig. 2*. The assumed segregation constant for indium, $k = 0.001$, is probably too high since it applies only when a very small percentage of indium is present. The value of emitter and collector doping is higher by a factor of 6, than Seed's [34] experimental results. Calculation of the impurity diffusion that takes place during the firing of such a unit shows that the transitions from emitter and collector to base are so abrupt as to be effectively completed within a distance of about 100 atom layers. Such a step junction




*Processing assumptions:*

Bulk impurity concentration: $N_{D1} = 2 \times 10^{15}$ atoms/cm³
Simultaneous alloying of dots containing acceptor impurity (indium)
Interface concentration (dot molten): $N_{A1_0} = 2.6 \times 10^{22}$ atoms/cm³
Firing temperature: 700 °C.
Firing time: to equilibrium

*Calculation assumptions:*

Cylindrical dots $\left(g = \dfrac{|x| - 0.2}{W_{regrown}}\right)$

Acceptor density (simple freezing): $N_{A1} = k\, N_{A1_0}\, (1-g)^{k-1}$
Segregation coefficient: $k \cong 0.001$
Donor density: $N_{D1}$ = constant

*Resultant profile:*

$N_{D1} + N_{A1}$

**Fig. 2—Fusion-alloy transistor. (p-n-p germanium)**

is ideal for optimizing emitter efficiency. On the other hand, it causes collector capacitance per unit area to be high.[6]

*B. Diffused Emitter and Collector* [27]

A transistor very similar to the fusion-alloy unit, but using only the diffusion principle, is pictured in *Fig. 3*. In the interest of emitter efficiency[7] and transport factor,[8] it is desirable to have the emitter junction

[6]The micro-alloy transistor is a fusion alloy type. It differs from *Fig. 2* only in that the regrown regions are very thin.

[7]The profile dependence of emitter efficiency is determined by the ratio of the number of impurities in the emitter region (within one minority carrier diffusion length) to the number in the base region.

[8]The opposing field in the base region, created by the positive impurity gradient near the emitter junction reduces the carrier velocity. Therefore, recombination in the base region increases and the transport factor and high frequency response are lowered.

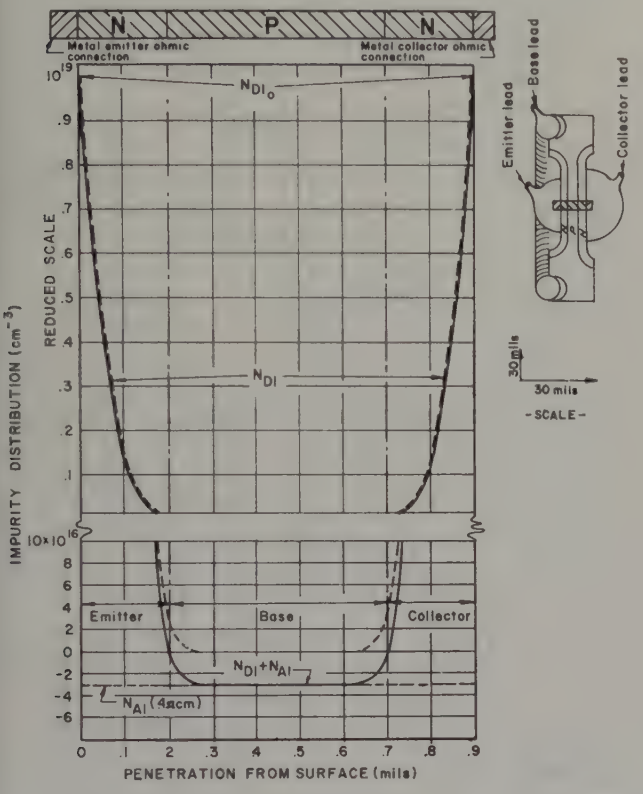
as abrupt as possible. Since surface concentration is limited by the metallurgical properties of the doping alloy, such an abrupt junction is possible only if the emitter penetration is relatively shallow.

A noteworthy electrical feature of both the fusion-alloy transistor and the unit which has been diffused from both sides is the low saturation resistance made possible by their potential impurity symmetry.

The preceding two types make exclusive use of the segregation and diffusion principles respectively with these processes taking place on both sides of the original piece of semiconductor. The following two examples again make use of either segregation or diffusion exclusively, but these processes take place on only one side of the semiconductor wafer.

*C. Meltback* [18]

The meltback process involves melting one end of a crystal bar, specially doped with donor and acceptor impurities (by a fast growing process), and resolidifying from the solid-liquid interface to achieve resegre-




*Processing assumptions:*

Bulk impurity concentration: $N_{A1} = 3 \times 10^{16}$ atoms/cm³

Simultaneous vapor diffusion of donor impurity (phosphorus) into bulk from both sides

Diffusion temperature: 1200 °C.

Diffusion time: 70 minutes

Diffusion coefficient: $3.5 \times 10^{-12}$ cm²/sec.

Surface concentration: $N_{D1_o} = 10^{19}$ atoms/cm³

*Calculation assumptions:*

Acceptor density: $N_{A1}$ = constant

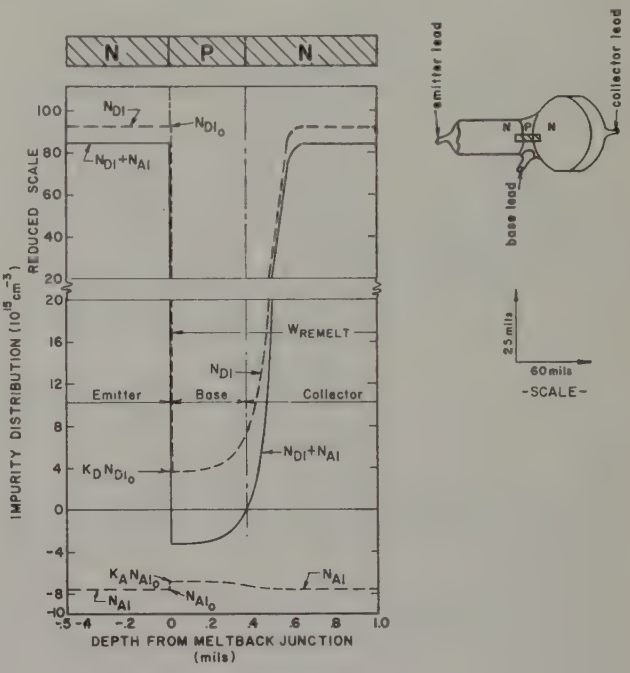
Donor density:

$$N_{D1} = \begin{cases} N_{D1_o}\, erfc \dfrac{x}{2\sqrt{D_p t}} & (x < 0.45) \\ N_{D1_o}\, erfc \dfrac{0.9-x}{2\sqrt{D_p t}} & (0.9 > x > 0.45) \end{cases}$$

*Resultant profile:*

$N_{D1} + N_{A1}$

**Fig. 3—Diffused emitter and collector transistor. (n-p-n silicon)**




*Processing assumptions:*

Original bulk impurity concentrations:

$N_{A1_o} = 7.5 \times 10^{15}$ atoms/cm³

and $N_{D1_o} = 9.25 \times 10^{16}$ atoms/cm³

Rapid crystal growth — melt containing acceptor impurity (boron) and donor impurity (antimony)

Meltback and quench

*Calculation assumptions:*

Constant cross-sectional area of bar $\left(g = \dfrac{x}{W_{remelt}}\right)$

Growth rate: $w\dfrac{dg}{dt} = 0.34\, e^x - 0.33$ mils/sec. (see text)

Acceptor density: $N_{A1} = k_B\, N_{A1_o}\, (1-g)^{k_B - 1}$

Segregation coefficient*: $k_B = \begin{cases} 1 & (x < 0) \\ f\left(w\dfrac{dg}{dt}\right) & (x > 0) \end{cases}$

$k_{B_o} = 0.9$

Donor density: $N_{D1} = k_{Sb}\, N_{D1}\, (1-g)^{k_{Sb}-1}$

Segregation coefficient*: $k_{Sb} = \begin{cases} 1 & (x < 0) \\ f\left(w\dfrac{dg}{dt}\right) & (x > 0) \end{cases}$

$k_{Sb_o} = 0.04$

*Resultant profile:*

$N_{A1} + N_{D1}$

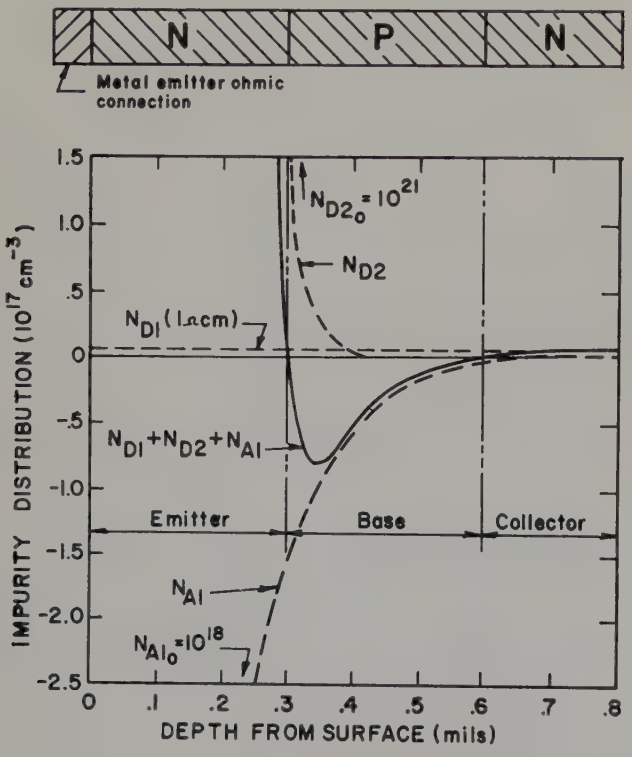
*See reference [7], Dacey, page 25.

**Fig. 4—Melt-quench transistor. (n-p-n silicon)**

gation of the impurities. Proper choice of both impurity concentrations and segregation coefficients is necessary to form the transistor structure. It is customary to use a melt-quench process, whereby during the cooling of the melted section the segregation factors increase steadily and cause the collector junction to be formed near the emitter-base junction. The quench rate is complex; therefore an engineering approximation has been used in the calculation of *Fig. 4*. The growing rate is approximated by an exponential function over the length of the remelted section of the bar. The dependence of the segregation constant on growing rate is taken from Burton and Slichter. [5]

The resulting electrical qualities are relatively inflexible since emitter efficiency, base resistance, etc. cannot be modified to any great extent. On the other hand, very small basewidths are possible, giving good high-frequency characteristics.

A still more limited modification of the meltback process is the slow cooled meltback transistor in which the collector junction and its position depend upon the equilibrium segregation coefficients. This device is of theoretical interest, but narrow basewidths are very difficult to achieve since very few doping elements have the proper segregation coefficients.




*Processing assumptions:*

Bulk impurity concentration: $N_{D1} = 5 \times 10^{15}$ atoms/cm$^3$
Simultaneous vapor diffusion of acceptor impurity (indium) and donor impurity (antimony) into bulk
Diffusion temperature: 1300 °C.
Diffusion time: 4 hours
Diffusion coefficients: $D_{In} = 10^{-11}$ cm$^2$/sec.
and $D_{Sb} = 1.4 \times 10^{-12}$ cm$^2$/sec.
Surface concentrations: $N_{A1_o} = 10^{18}$ atoms/cm$^3$
and $N_{D2_o} = 10^{21}$ atoms/cm$^3$

*Calculation assumptions:*

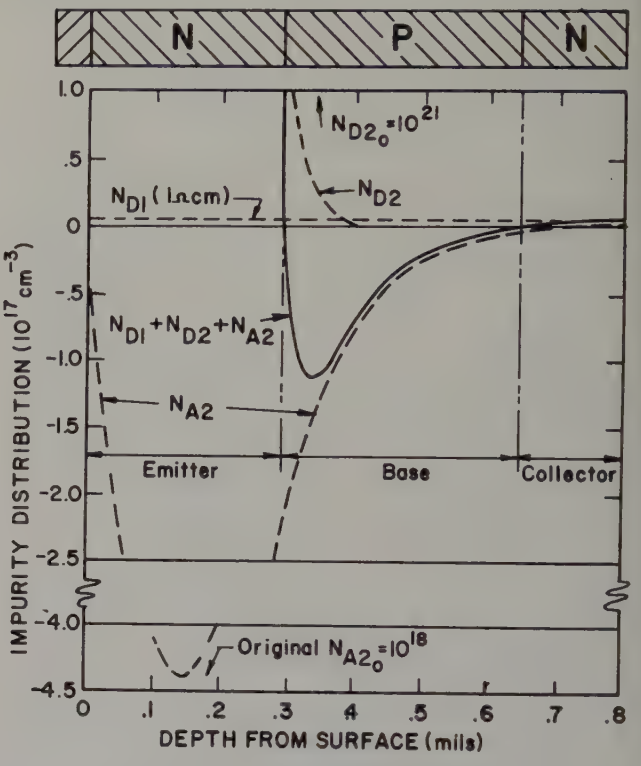
Acceptor density: $N_{A1} = N_{A1_o}\, erfc \dfrac{x}{2\sqrt{D_{In}\, t}}$

Donor density: $N_{D2} = N_{D2_o}\, erfc \dfrac{x}{2\sqrt{D_{Sb}\, t}}$

*Resultant profile:*

$N_{D1} + N_{D2} + N_{A1}$

**Fig. 5a—Transistor with diffused base and emitter, (simultaneous diffusion). (n-p-n silicon)**




*Processing assumptions:*

Bulk impurity concentration: $N_{D1} = 5 \times 10^{15}$ atoms/cm$^3$
Vapor diffusion of acceptor impurity (indium) into bulk
Diffusion temperature: 1300 °C.
Diffusion time: 4 hours
Diffusion coefficient: $10^{-11}$ cm$^2$/sec.
Surface concentration: $N_{A1_o} = 10^{18}$ atoms/cm$^3$
Vapor diffusion of donor impurity (antimony) into bulk
Diffusion temperature: 1350 °C.
Diffusion time: 1 hour
Diffusion coefficient: $5.6 \times 10^{-12}$ cm$^2$/sec.
Surface concentration: $N_{D1_o} = 10^{21}$ atoms/cm$^3$

*Calculation assumptions:*

Acceptor density: $N_{A2}$ = modification of $N_{A1_o}\, erfc \dfrac{x}{2\sqrt{D_{In}\, t_{In}}}$ allowing for slump effect resulting from subsequent diffusion

Donor density: $N_{D1}$ = constant

and $N_{D2} = N_{D2_o}\, erfc \dfrac{x}{2\sqrt{D_{Sb}\, t_{Sb}}}$

*Resultant profile:*

$N_{D1} + N_{D2} + N_{A2}$

**Fig. 5b—Transistor with diffused base and emitter, (sequential diffusion). (n-p-n silicon)**

*D. Diffused Base and Emitter* [39]

This transistor is made by vapor diffusing donor and acceptor impurities simultaneously (*Fig. 5a*) or sequentially (*Fig. 5b*) into the bulk. The resultant of the two diffusions creates the emitter-base-collector profile. The units created by this technique are relatively inflexible because the superposition of the two profiles introduces a number of limitations. For example, it is preferable for the base to be lightly doped, since the current amplification factor is highly dependent upon base doping, due to lifetime degeneration at high doping levels. On the other hand, light base doping results in high $r_{b\ extr}$ because the base region extends beyond the active emitter junction (see mechanical structure, *Fig. 6*). It would also be desirable to reduce the effect of the opposing field on the emitter side of the base in order to improve current-amplification and high-frequency performance.[8] The steep emitter gradient necessary to minimize this field can only be realized from the diffusion phenomenon if the diffusion depth is kept to a minimum. This restriction on diffusion depth puts a severe limitation on emitter efficiency.[7]

The simultaneously double-diffused device assumes complementary error functions for the acceptor and donor vapor diffusions. The impurity distribution $N_{A2}$ in the sequentially diffused device, however, is substantially altered (see *Fig. 6* for comparison) because of an out-diffusing of the first impurity during the second diffusion. Consequently, the modified $N_{A2}$ is of such complex form that analytic derivation was deemed impractical; the curve in *Fig. 5b* is the result of an analog computation. [42]

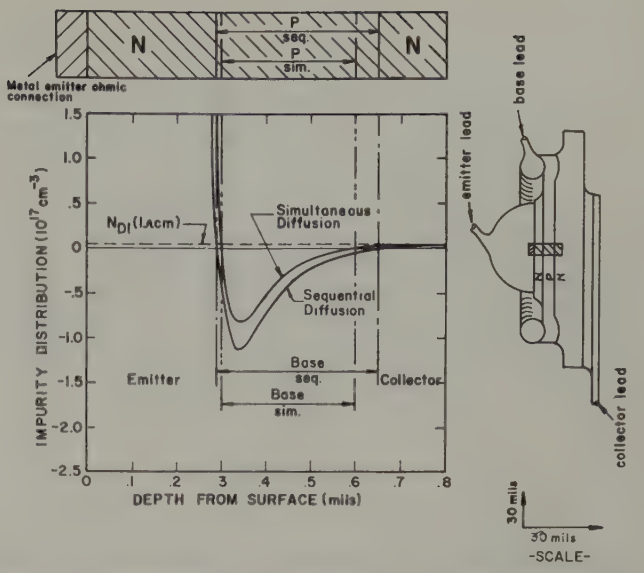



**Fig. 6—Comparison of simultaneously and sequentially diffused base and emitter transistors, (n-p-n silicon). Profiles are taken from Figs. 5a and 5b.**

The six remaining profiles show the impurity distributions when both the diffusion and segregation phenomena are utilized.

[7]Ibid.
[8]Ibid.

[*To be continued*]

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**List of Symbols**

$V_{min}$ — In an intrinsic region transistor the minimum voltage required for the space charge to widen across the intrinsic region.

$k$ — The segregation coefficient (ratio of impurity concentration in the solid to that in the liquid at the interface).

$g$ — That fraction of the original volume which has solidified.

$D$ — The diffusion coefficient.

$\alpha_{fe}$ — The small signal short-circuit forward current transfer ratio. (common emitter)

$\alpha_{rb}$ — The small signal short-circuit reverse current transfer ratio. (common base)

$r_{b\ extr.}$ — Extrinsic base branch resistance.

$f_{\alpha b}$ — The frequency at which the magnitude of $\alpha_{fb}$ is .707 of the low frequency value.

$C_C$ — Collector capacitance.

$V_p$ — The voltage at which the space charge region extends from the collector to the emitter junction.

$BV_{CB}$ — The avalanche breakdown voltage from collector to base, emitter open circuited.

$V_{SAT}$ — Saturation voltage or voltage measured from collector to emitter when the transistor is operating in the saturation region.

# Some Effects of Semiconductor Surfaces On Device Operation

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**Practically all semiconductor devices utilize the electrical characteristics of the *p-n* junction for their operation. In general, these characteristics are influenced by the physical-chemical structure at the semiconductor surface. The reverse current of diodes and the power gain, current gain and frequency cutoff of transistors can be severely limited by surface conditions. The understanding and control of semiconductor surface properties is of great value in the design and fabrication of devices. The study of the surface involves the outer layers of the bulk material, any adsorbed films of foreign material and the surrounding ambient.**

PRODUCTION TECHNIQUES of semiconductor devices have advanced to a point where it is feasible to develop a device to have certain specialized characteristics. That is, using semiconductor theory, one can design a device and be reasonably certain that the specifications as to semiconductor purity and geometry will be met. However, it has often happened that a device has failed to exhibit the desired characteristics not because design specifications were inadequate or unfulfilled, but rather because of the effect of semiconductor surface behavior.

Much of the work which led to the discovery of transistor action was concerned with surface effects on semiconductor rectifying properties. In 1947, Bardeen[1] suggested that electronic states or charged sites on the semiconductor surface could account for the then puzzling observed behavior of semiconductor-metal contacts. After this, Brattain and Shockley[2] found experimental evidence for surface states from contact potential measurements on semiconductors.

Later, Shockley and Pearson[3] showed that the modulation of the conductance of a semiconductor sample by a transverse electric field was much less than expected and explained the results in terms of surface states.

In the years that followed, most semiconductor research and engineering was concerned with bulk properties. However, here and there projects were undertaken to investigate surface behavior, and with time their number increased, so that in the last few years there have been many groups engaged in surface studies. These surface studies have confirmed the existence of Bardeen's surface states, taught us much of their structure, and demonstrated their effects on the operating characteristics of devices.

Semiconductor conductance characteristics follow from the behavior of mobile charged carriers (holes and electrons), whose relative densities in the material are controlled by doping the semiconductor with small amounts of impurities. The effect of a negative surface charge on the carrier density of *n*-type material near the surface is indicated in *Fig. 1*. Here electrons are pushed away from the surface, exposing a space charge layer of immobile, positively charged donor atoms which tend to neutralize the surface charge. If the surface charge density is quite high, then it is also necessary for holes to be drawn to the surface to preserve neutrality, and a conducting *p*-type surface layer or "inversion" layer is produced. In a similar manner, positive charges on *p*-type material can produce an *n*-type surface inversion layer. Positive surface charge on *n*-type material or negative surface charge on *p*-type material would, of course, attract the majority carriers, electrons or holes, respectively, toward the surface producing a region of excess majority carrier density, sometimes called an "accumulation" layer. This modulation of carrier density at the surface by charges in surface states would indicate that surface states affect device operation.

A transistor is essentially an interacting combination of two diodes in one piece of semiconducting material, so that it might be appropriate to consider first the effect of surface conduction on diode characteristics. To make a diode operative it must be cleaned after fabrication so that all surface work damage and conducting contaminants are removed. However, even a carefully cleaned and etched diode may not exhibit the expected voltage, current and capacitance characteristics. Curve *1* in *Fig. 2* represents the desired characteristics of some reverse biased diode, i.e., the reverse current saturates over the operating range. Sometimes different operating characteristics are observed, such as:

1. As shown in curve 2, the reverse current may saturate but at a value higher than that predicted by the bulk properties.

2. As shown in curve 3, the reverse current may not saturate but rather may vary approximately as

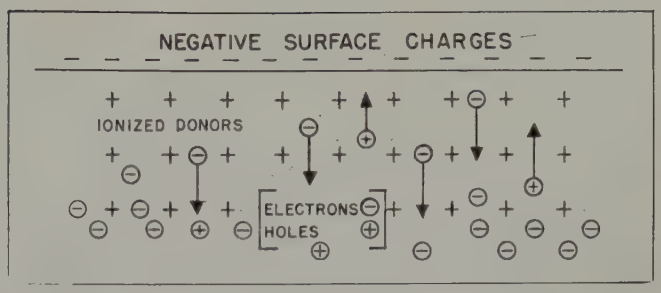


**Fig. 1—The effect of negative surface charge on an *n*-type semiconductor.**

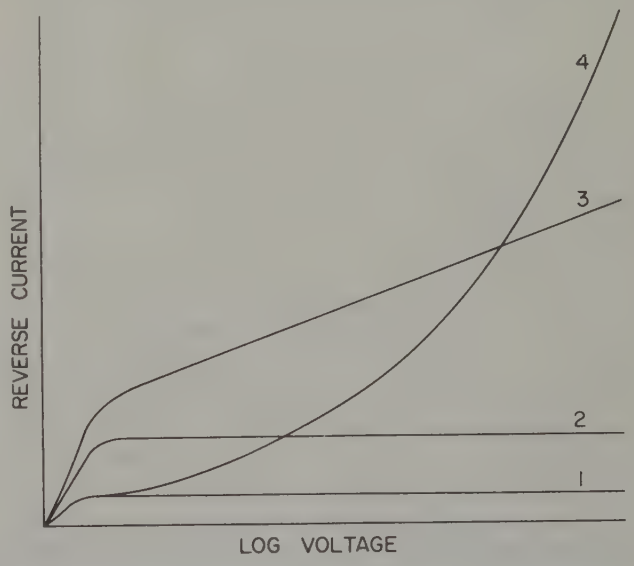


**Fig. 2—Various observed reverse diode characteristics.**

the logarithm of the voltage. In such a case the current takes seconds or minutes to reach a stable value when the voltage is changed suddenly. This behavior is sometimes referred to as "creep." In addition, the capacitance of such a unit may be much higher than that expected from the bulk properties.

3. As shown in curve 4, the reverse current may show close to a linear increase with voltage at voltages well below the breakdown voltage, and creep is often observed.

Let us consider the first case, where the saturation current is high. This saturation current arises from the diffusion of minority carriers in the vicinity of the junction. The magnitude of this diffusion current, per unit area, is dependent on a number of factors, one of which is recombination lifetime.

It is a property of semiconductors that if a number of minority carriers in excess of the equilibrium number are somehow placed in the material, this excess number will immediately start to diminish through the process of recombining with majority carriers and will continue to diminish in an exponential manner until equilibrium is restored. Thus, the density of minority carriers diffusing toward the space charge region at the junction will die out exponentially as it approaches the junction area. The exponential decay can be represented by a time constant called the recombination lifetime. The smaller this lifetime, the

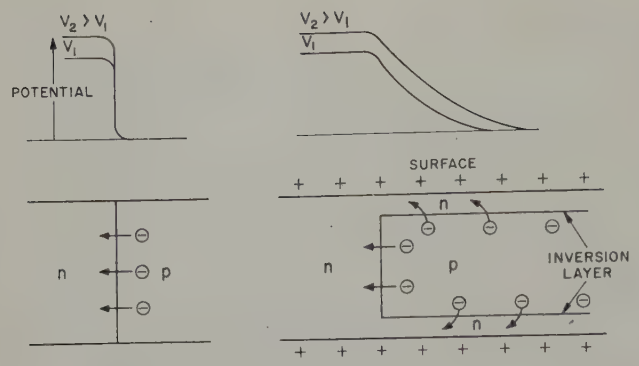


**Fig. 3—Effect of inversion layer on voltage drop across *p-n* junction.**

greater will be the gradient in the number of excess minority carriers as a function of distance away from the junction, and since the diffusion current is proportional to this gradient, we see that short lifetimes lead to high saturation currents.

To bring the surface condition into the picture, it is now necessary to point out that an effective recombination lifetime results from recombination in the bulk and at the surface. The relative contribution of each will depend on the geometry, in particular on the surface-to-volume ratio, of the specimen. The effect of surface recombination becomes more important as the surface-to-volume ratio increases and, since this ratio becomes larger as the overall size of a device diminishes, the very fact that semiconductor devices are so small makes them surface-sensitive. The bulk recombination will be fixed for any given material, but surface recombination may vary greatly with the condition of the particular surface. The surface can be characterized in this respect by a parameter called the surface recombination velocity, which is the ratio of the number of carriers per unit area per unit time recombining at the surface to the number per unit volume available just beneath the surface. Thus, a high surface recombination velocity corresponds to a low value of surface lifetime. On germanium, a rough or strained surface, such as would be produced by sandblasting or grinding, will have a high surface velocity (up to $10^4$ cm/sec.), whereas the surface velocity will be quite low (50-200 cm/sec.) on the surface resulting from chemical etching.

The second phenomenon, the observed slow increase in reverse diode current with voltage, may be due to the formation of a surface inversion layer. This surface inversion layer, of course, forms a junction with the bulk material and thus extends the area of the original junction. This added junction is effective as a collector of carriers only in that region where there is a voltage drop across it. Normally, the voltage drop on a reverse-biased diode is confined to a very narrow region at the junction, but with an inversion layer or "channel" present, this drop is spread out, depending on the conductance and current in the channel. (See *Fig. 3.*) This effective added junction area will vary with applied voltage, and so too will the diode reverse current which now includes the saturation current of the bulk junction and the saturation current of the surface junction.

Visual evidence of this spreading out of the potential drop at the junction is shown in *Fig. 4,* which is a microphotograph† of the area in the vicinity of an arsenic diffused *p-n* junction. On the electrolytically etched surface, the bright lines at the junction are due to sharp doping impurity gradients. With an inversion layer present on the *p*-type region, barium titanate particles, which tend to deposit where there is a potential gradient along the surface,[4] are seen to be spread out away from the junction.

Since, in general, the saturation current of the surface junction is much greater than that of the bulk junction, because many of the surface states are generation-recombination centers, the voltage dependence of the effective area of the surface junction will describe the voltage dependence of the total diode current. From a knowledge of the variation of inversion layer conductance as a function of the potential drop across the surface junction at any point, the distribution of potential along the surface junction and thus the area over which the saturation current is collected has been determined. Such calculations, which have been confirmed by experimental data, indicate that the reverse current varies approximately as the logarithm of the reverse voltage applied to the diode.[5] Of course, as the effective junction area increases so does the total diode capacitance.

As stated earlier, the inversion layer results from charges residing on the surface. Now it turns out that there are two places that this surface charge can appear: first at the interface between the semiconductor and semiconductor oxide film, which forms after chemical or electrolytic etching, and second, on or in the oxide. (See *Fig. 5.*) The charges in these posi-

†Courtesy of P. Levesque, Research Division, Raytheon Manufacturing Co.

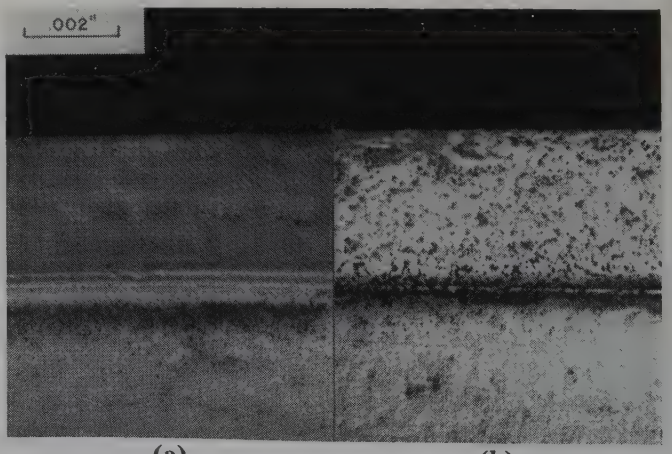


**Fig. 4—Microphotographs of an arsenic-diffused germanium *p-n* junction with (a) barium titanate deposited on inversion layer in the *p*-type region and (b) barium titanate deposited on the junction after removal of inversion layer.**

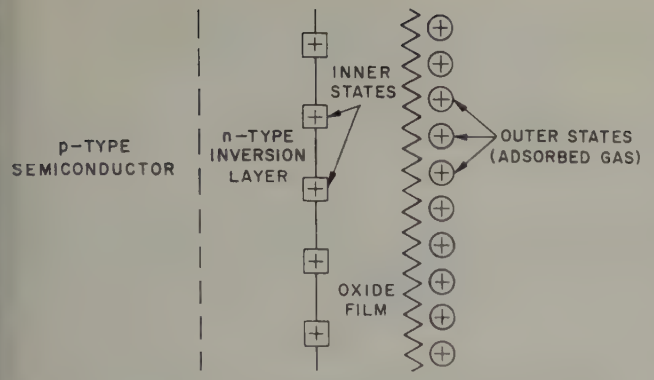


**Fig. 5—Positions of semiconductor surface states.**

tions or sites are electronically in communication with the bulk material. The occupancy of the interface positions reaches equilibrium in a matter of millimicroseconds, whereas that of the oxide positions may take some minutes to come to equilibrium, which accounts for the observed drift in current following the application of, or a change in, bias voltage. In general, the density of the interface states is insufficient to modulate to a significant degree the surface conductivity of device material, but rather it is the readily attainable, much higher, density of outer states which control the surface.

The charge residing in or on the oxide film is often produced by adsorbed gas molecules which lose or gain charge. The gases which are most likely to affect devices are oxygen, which produces a negative surface charge, and water vapor, which produces a positive charge. Now, if a diode is exposed to a high humidity ambient, many layers of water molecules may sit on the surface. The positive charge on these adsorbed molecules will cause inversion layer formation on *p*-type material. When a number of layers of liquid vapor molecules are present so as to form a coherent film, the positive charge becomes mobile. It is believed that this is an electronic process where only the charges move, rather than an ionic one where the molecules move. Surface charge mobility, then, accounts for the third type of unusual reverse diode current behavior.

The potential distribution at the junction, as indicated in *Fig. 6a,* is such as to force the mobile positive surface charge on the *p*-type region away from the junction. When the surface charge density near the junction is thus reduced, the inversion layer conductivity is also reduced in that area, and an even greater potential drop results causing further movement of the positive charge. Eventually, this process comes to equilibrium with the potential and surface charge distribution as indicated in *Fig. 6b.* The voltage across the surface junction is now everywhere considerably reduced from the total applied voltage; so much reduced at low bias values that the collection of carriers at the surface junction is reduced. Now, as the bias voltage is increased, more and more carriers are collected at the surface junction so that the reverse current of the diode is seen to increase almost linearly with voltage. There is evidence that the liquid on the surface acts in some manner so as to increase markedly those interface states which are recombination-generation centers, thereby increasing the surface velocity,[6,7] and thus the surface junction saturation current. Very large and unstable reverse currents are observed, therefore, when liquid films are present. Water vapor is by no means the only source of liquid film effects; the same effects have been observed with methyl alcohol, acetone and dioxane.

The effect of surface behavior on transistor operation can best be illustrated by considering a simple grown junction device. (See *Fig. 7.*) Of course, most devices have a more complex geometry, but the principles will still apply. Here is an *n-p-n* unit with a grounded base. The first junction, biased in the forward (low impedance) direction, emits electrons into the base region, where they become minority carriers. After traversing the base region, most of these electrons are collected at the second junction, biased in the reverse (high impedance) direction. This process whereby a current, which can be modulated, enters the base region through a low impedance and leaves substantially undiminished through a high impedance, makes the transistor a power amplifier. For good power amplification, one would like to have a high efficiency of emission and collection and as few carriers as possible lost while traversing the base region. The surface lifetime in the base region can be quite important here. High surface velocities in this region will raise the collector saturation current and, as shown in *Fig. 7,* lower the percentage of emitted carriers that successfully traverse the base region. Oper-

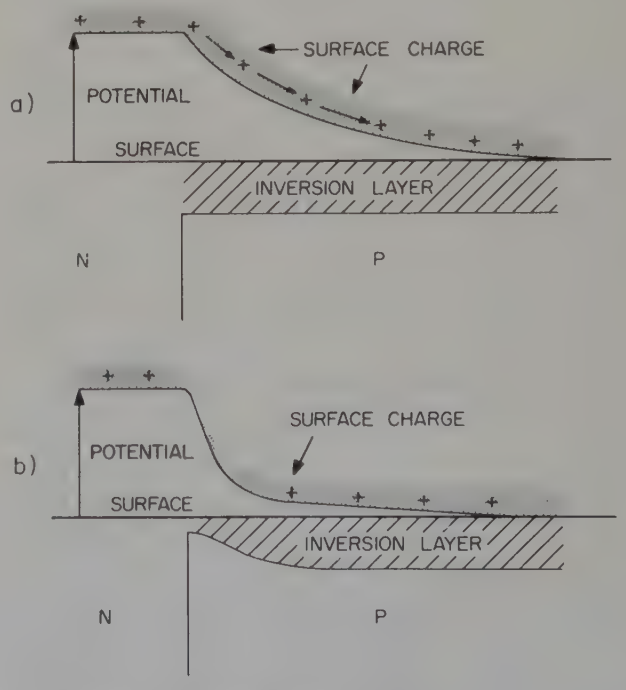


**Fig. 6—Effect of mobile surface charge on voltage drop across *p-n* junction.**

ated as a grounded emitter unit, the transistor becomes a current amplifier, and it is seen from *Fig. 7* that reducing the surface lifetime in the base region is detrimental to this type of operation since it increases the base signal current and lowers the collector signal current.

It is of some interest to indicate in more detail the effect of surface behavior on $h_{fe}$ (the ratio of collector to base signal currents). $h_{fe}$ can be related to $h_{fb}$ (the ratio of collector to emitter signal currents) by the expression

$$h_{fe} = \frac{h_{fb}}{1 - h_{fb}} .$$

Webster[8] has expressed $h_{fe}$ for the alloy-junction transistor in terms of semiconductor parameters and shows that it depends on three terms, such that

$$\frac{1}{h_{fe}} = s\, A_s\, X + Y + Z,$$

where $s$ is the surface recombination velocity, $A_s$ is the effective area at which surface recombination occurs, $X$ is a constant and $Y$ and $Z$ are terms involving emitter efficiency and volume recombination. As is shown in Table I, taken from a recent article[9] using Webster's notation, $X$ and $Y$ can be considered as constants here. It is clearly seen that the surface term is critical and that variations in $s$ or $A_s$ (due to inversion layer formation) markedly affect $h_{fe}$.

An effective inversion layer (i.e., that portion where there is enough voltage drop to collect carriers) on the base region will increase the collector saturation current and the collector capacitance. The latter effect will limit the frequency cut-off value. Of course, if an effective inversion layer should extend all the way from the collector to the emitter, the transistor action would be diminished to a degree depending on the magnitude of the channel resistance, which may vary greatly.

The nature of semiconductor surfaces in terms of electronic states and adsorbed material has evolved from many lines of research. The electrical properties of surfaces have been determined using both homogeneous samples and device-like structures. The necessary high density of surface charge has been produced by surface exposure to various ambient gases such as oxygen, ozone and ammonia or by electrostatic induction. Surface contact potential, surface layer conductance and surface recombination of photo generated carriers are some of the properties measured. The physical-chemical nature of the semiconductor surface has been studied by following reactions on clean surfaces produced in vacua in the range of $10^{-10}$ *mm* of mercury. Clean surfaces have been produced by bombardment with ions of chemically neutral gases or by crushing the material in vacuum. Adsorption processes have been determined by following pressure changes, weight changes using microbalances capable of less than a monolayer of adsorbed gas sensitivity and structure changes using low energy electron beam diffraction techniques. Detailed accounts of many of these studies may be found conveniently grouped in *Physica,* Vol. *XX,* No. 11, 1954, and *Semiconductor Surface Physics,* University of Pennsylvania Press, 1957.

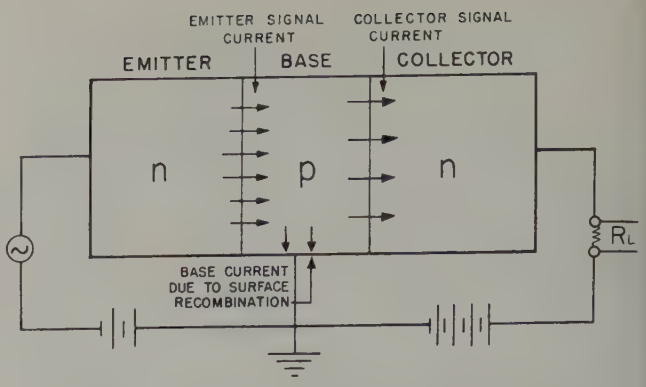


**Fig. 7—*n-p-n* transistor (grounded base)**

**Table I**

| UNIT | $sA_sX$ | Y | Z | $h_{fe}$ |
|---|---|---|---|---|
| 1 | 0.025 | 0.001 | 0.0006 | 37 |
| 2 | 0.007 | 0.005 | 0.0001 | 128 |
| 3 | 0.006 | 0.001 | 0.0003 | 116 |

The continued study of semiconductor surface behavior is desirable if the demonstrably surface-sensitive devices are to exhibit optimum characteristics. For future device designs and uses, particularly at higher temperatures, more knowledge of surface phenomena is indicated. Silicon devices, for instance, should in general perform quite well up to temperatures of 250°C, but such high temperature operation is limited by surface instability. An understanding of semiconductor surface phenomena is important, not only for device development, but also as an aid in determining surface properties of all solid state materials.

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# The Advantages of Tetrode Geometry For Power Transistors;

# Stability and Control of Amplified Leakage Current

HOWARD T. MOOERS* RICHARD J. ZELINKA*

**It is difficult to attain low values of common emitter circuit leakage using high impedance inputs for triode transistors, without severely lowering the normal stage gain. The power tetrode has two isolated base connections. One is used to insert the signal, the other to establish the desired no-signal leakage condition. If one base is connected to the emitter or restrained by a voltage equal to the floating potential, the common emitter leakage is essentially reduced to $I_{CES}$ and $I_{CBO}$ respectively, without materially affecting the transfer function. A circuit example is given which illustrates the advantage of the tetrode over the equivalent triode configuration.**

ALL TRANSISTORS have a leakage current dependent upon the junction area. Power transistors have a large junction area to handle the currents involved and consequently have rather large leakage currents. This is compounded by the fact that the leakage current doubles every 9°C, and, in the common emitter configuration, the leakage current is multiplied by the current gain of the device.

The actual value of the leakage current depends upon the transistor, its temperature, the applied voltage, and the particular circuit configuration. Examination of the leakage characteristic leads to the construction of several leakage curves which may be used for reference.

### Leakage Characteristics of a Triode

Using the circuit shown in *Fig. 1*, the leakage characteristics can be examined for a large number of circuits. Of these characteristics, several are significant. The characteristic curves are shown in *Fig. 2* and are generated using the following resistance values:

1. $R_E = \infty$, $R_B = 0$, Curve $I_{CBO}$
2. $R_E = 0$, $R_B = 0$, Curve $I_{CES}$
3. $R_E = 0$, $R_B = \infty$, Curve $I_{CEO}$

The values read as $V_C$ are not exactly the collector voltages, as such, but are the circuit voltages, most of which appear on the collector. There are small potential drops across the input resistors and the meter which may generally be neglected.

The leakages under zero input conditions are limited to the region between $I_{CBO}$ and $I_{CEO}$. The first is generally associated with the open emitter leakage of the common base configuration, while the second is regarded as the open base common emitter leakage. The two leakage values are related as follows:

$$I_{CEO} = I_{CBO}\,(\alpha_{CB} + 1)$$

### Circuitry Modifies These Leakages

In actual practice neither of these input terminals is left open in an operating circuit, so that these curves do not represent the normal expected leakage of the device in a circuit. Any *d-c* connection to the input of a common base transistor causes the emitter lead in-

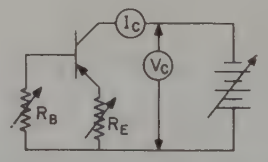


**Fig. 1—Circuit for measuring leakage currents.**

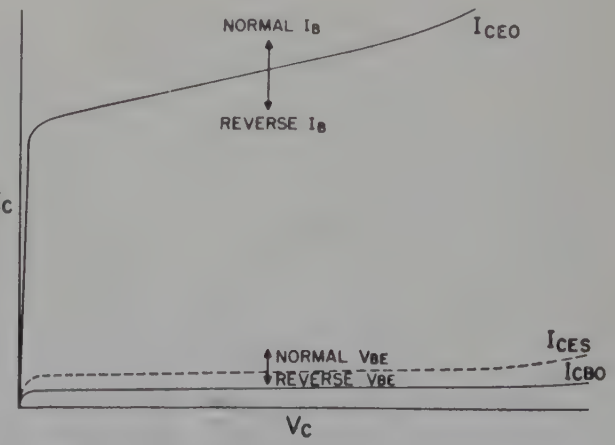


**Fig. 2—Reference leakage characteristics.**

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put resistance to be less than infinity, and the leakage current will increase from $I_{CBO}$. The common base leakage finally becomes $I_{CES}$ (or $I_{CBS}$) when zero resistance appears between the emitter and base. The common emitter circuit shows a leakage equal to $I_{CEO}$ when the base lead is open. As the base lead resistance is decreased, the leakage current decreases until it reaches the value of $I_{CES}$ as the resistance from base to emitter approaches zero.

The value of $I_{CES}$ is usually several times the value of $I_{CBO}$ and is dependent upon the internal resistances associated with the base and the emitter.

In any circuitry, if the collector leakage current $I_{CBO}$ is entirely provided by the base lead, the emitter current becomes zero and the collector current is just $I_{CBO}$. If the base circuitry cannot or does not supply the required $I_{CBO}$, the remainder will be supplied through the emitter, and this part will then be multiplied by $(\alpha_{CB} + 1)$. Thus, the ratio of $I_{CES}$ to $I_{CBO}$ will be higher for high base resistance units and lower for units with high emitter resistance. The internal lead resistances tend to establish the ratio of division of leakage current between the base and emitter, and thus establish the proportion of leakage current which is amplified.

Obviously, then, the leakage value of $I_{CES}$ can be duplicated with resistors in both the base and emitter leads, provided they are in the inverse ratio to the base and emitter currents. Thus, the voltage drop will be equal for both the base and emitter resistors, and the net voltage appearing at the transistor between the base and emitter terminals will be zero. Circuitwise, these values of emitter resistance are usually too high to be of value because they seriously limit the available output.

The same theory holds for other cases involving resistors in both the emitter and base lead paths. If the leakage current is supplied through the base lead, the emitter current will be zero, and the total circuit leakage will be $I_{CBO}$. The ease with which the amplified leakage current can flow to the emitter will determine the increase of leakage over $I_{CBO}$ until the limit is reached where no leakage is supplied by the base and thus the total leakage is amplified. It is for reasons of limiting the value of amplified leakage that emitter resistors are used. Their use, however, reduces the amount of the supply voltage that can be impressed across the load. Thus, even though the leakage currents can be reduced by an emitter resistor, it is seldom feasible to reduce it very far, certainly not to the level approaching $I_{CBO}$.

It can be seen that the effectiveness of the emitter resistor is influenced by the magnitude of the base resistor. The emitter resistor can do no good when the base is open or terminated in a high resistance. The stabilizing effect of the emitter resistor is greatest when the base lead resistance is as low as possible.

Under active circuit conditions when biases or signals are applied, the leakage may also be evaluated. The common base leakage current causes an open emitter to assume a small potential with respect to the base. This is called the emitter floating potential. If this potential is applied between the emitter and base in the common emitter circuit, the base will supply all of the leakage current, and the emitter current will be zero. Thus, in the common emitter circuit, when the base is back biased by the amount of the floating potential, the circuit leakage is reduced to $I_{CBO}$. Further back bias does little except to back bias the emitter junction also.

The transistor behaves according to the currents and voltages that are impressed upon it. A circuit may be nominally designed to provide a back bias, but if the magnitude of the available voltage, reduced by the leakage current flowing through the impedance of the source, does not at least equal the floating potential, the transistor is not cut off and a portion of the leakage becomes amplified. This effect is generally encountered at elevated temperatures when the leakage magnitudes are large.

#### Components of Leakage Current

The $I_{CBO}$ leakage current is made up of several components. The bulk semiconductor leakage or saturation current is dependent upon the junction area, resistivity of the collector and base materials, and temperature. It is this component which doubles every 9°C.

There is an ohmic component which appears to be dependent upon the periphery of the junction, the etching, cleanup, and surface treatments of the junction edge, voltage, and temperature. This ohmic leakage component increases with temperature. Its resistance value will decrease to perhaps 20% of its room temperature value when the junction is at 95°C.

A third component is due to the avalanche effect or body breakdown and it occurs at high voltages. This causes the bending of the leakage characteristic prior to breakdown. Body breakdown is due to the multiplication of charge carriers due to collisions at high energy levels (i.e. high voltage). The body breakdown or avalanche voltage is often defined as the voltage where $\alpha_{CE} \rightarrow \infty$. The voltage where this action takes place must be well above the normal operating voltages, and the phenomenon appears to be a function of the voltage gradient within the junction. The breakdown voltage has a positive temperature coefficient—the higher the temperature, the higher the voltage.

These several leakage components may be roughly separated at room temperature as follows: A low voltage leakage measurement will eliminate a large portion of the ohmic component and all of the avalanche increase. This current, when doubled every 9°C, will predict a maximum leakage current for any temperature. Due to the unavoidable inclusion of some of the ohmic component, the expected current will be somewhat less than predicted.

The ohmic component of current increases with both voltage and temperature because the effective shunting resistance decreases with temperature. The temperature coefficient of this leakage is smaller and may usually be neglected unless the slope of the leakage characteristic is important. The ohmic component may be measured by the difference in leakage currents at any two voltages at the same temperature, provided that the two points are selected below the start of curvature due to multiplication or avalanche effects.

### Voltage Breakdown Phenomena

The breakdown characteristic may be observed by an oscilloscope and a current limited pulse. Either the breakdown voltage or the voltage at which the leakage curve begins to depart from an ohmic characteristic may be measured by this technique. Since these voltages increase with temperature, high temperature operation is not a problem as far as body breakdown is concerned.

The leakage currents for a shorted base-to-emitter connection increase faster than the values of $I_{CBO}$. In the common base configuration it can be shown that the emitter floating potential increases with temperature. By providing a short circuit path between the base and emitter, a turn-on signal of the magnitude of the floating potential is inserted into the input of the transistor, and the value of $I_{CES}$ is therefore always greater than $I_{CBO}$. Due to the increasing floating potential with temperature, the rate of increase of $I_{CES}$ is also greater than for $I_{CBO}$. This type of breakdown can easily be observed because it is less than body breakdown. It occurs at a high collector voltage when the floating potential begins to increase.

The leakage currents for an open base circuit are dependent upon $\alpha_{CB}$. At these current levels, $\alpha_{CB}$ increases with current, temperature and voltage. The magnitude, slope, and maximum voltages of the leakage characteristic are thus governed strongly by variations in $\alpha_{CB}$. The slope of $I_{CEO}$ is not simply the slope of the $I_{CBO}$ curve multiplied by $\alpha_{CB}$; the slope is even greater due to the increase of $\alpha_{CB}$.

The maximum voltage for an open base condition where $\alpha_{CE} \rightarrow \infty$ is considerably less than body breakdown. At a considerably lower voltage than body breakdown, the multiplication factor makes the value of $\alpha_{CE} = 1$. Since

$$\alpha_{CB} = \frac{\alpha_{CE}}{1 - \alpha_{CE}}$$

the value of $\alpha_{CB}$ becomes infinite at a voltage considerably under the body breakdown. The leakage current $I_{CEO}$, near this voltage, where $\alpha_{CE} = 1$, increases radically with temperature so that it usually becomes an important parameter when the transistor is driven from a high resistance source. The voltage at which $\alpha_{CE} = 1$ varies little with temperature and operating point and is not affected by input resistance.

However, as with the leakages, these breakdown voltages do not necessarily act as a circuit limit. These lower breakdown voltages can be increased by back bias (at least in the region near cut-off) to the limit of body breakdown or punch through, whichever occurs first. The necessary input network or biasing arrangement is generally somewhat cumbersome and usually causes a disproportionate reduction in gain by either shunting the input or causing an input threshold level for the signal to overcome.

### Tetrode Advantages

These disadvantages are reduced by using a power tetrode. Consider what can be done by having two separate base connections available. One could be reserved for the signal input, while the other is used to establish the bias point or to supply the leakage current.

In the simplest case, one base could be connected to the emitter and therefore limit the leakage to the $I_{CES}$ curve, while the second base could be used as the signal input channel with only a moderate loss in current gain.

Other circuitry, necessary to stabilize the operating point and provide a temperature-sensitive bias, need not be concerned with shunting the input circuit nor with its changes in temperature due to signal level changes.

Another circuit possibility is to supply the collector leakage current through one base so that the stability of the common base configuration is achieved without losing the current gain of the common emitter circuit.

In these cases, not only is the leakage value reduced, but the associated voltage limit is increased, depending upon the leakage characteristic used. For example, if one base were used to supply the total leakage, its value and the voltage breakdown value would be as shown for the $I_{CBO}$ curve.

A further advantage is that the leakage current is generally independent of the signal source resistance. The leakage current does not change when the signal input base is either opened or shorted to the emitter. See *Fig. 3.*

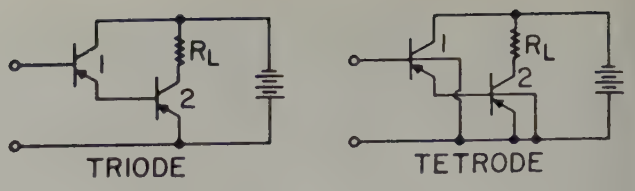
Direct-coupled triode circuits progressively multiply the leakage currents of the initial stages and often totally saturate the output unit. A simple tetrode connection removes the leakage from the signal path so that the total leakage of the direct-coupled cascade is essentially the unamplified leakage of the final stage. See *Fig. 4.* In this case, operation as tetrodes reduced the circuit leakage currents by a factor of at least 25.

### Circuit Example

Direct-coupled circuitry is used in the voltage regulator shown in *Fig. 5.* The circuit consists of an *n-p-n* transistor direct coupled to a *p-n-p* cascaded pair in which the output transistor is a power tetrode. The

| INPUT CIRCUIT | LEAKAGE CURRENT | |
|---|---|---|
| | TRIODE | TETRODE |
| OPEN INPUT | $I_{CEO}$ | $I_{CES}$ |
| SHORT CIRCUIT INPUT | $I_{CES}$ | $I_{CES}$ |
| INPUT SHUNT RESISTANCE | $I_{CES}$ TO $I_{CEO}$ | $I_{CES}$ |

**Fig. 3—Comparison of triode and tetrode leakages.**




ASSUME

$I_{CB01} = I_{CB02} = .5$ ma

$I_{CES1} = I_{CES2} = 1.0$ ma

$\alpha_{CB1} = \alpha_{CB2} = 50$

| INPUT CIRCUIT | LEAKAGE CURRENT | |
|---|---|---|
| | TRIODE | TETRODE |
| INPUT OPEN | 1,300 ma | 1.0 ma |
| INPUT SHORTED | 25.5 ma | 1.0 ma |

**Fig. 4—Direct coupled circuit comparison.**

performance of this circuit will be compared for triode and tetrode operation of the ouput transistor.

This voltage regulator is designed to supply 22 volts ±1% with input voltage variation from 24 to 32 volts and output load variation from zero to 3 amperes.

Regulators of this type are capable of maintaining control of the load voltage as the load current is decreased until the circuit is cut off and only the leakage current flows. However, if the load cannot consume the total leakage current, the output voltage will begin to rise toward the supply voltage. This characteristic is generally controlled by using a bleeder resistance across the output. Thus, the regulator never sees an open load, even when the actual load is removed. If the load does not change significantly, the bleeder may be omitted. However, if the load may decrease to zero, regulation will be lost unless a bleeder is provided which can accommodate the entire leakage current. Obviously, a higher capacity bleeder is required for operation at higher temperatures.

Triode operation of the output transistor in the circuit shown in *Fig. 5* can be achieved by either disconnecting base 2 entirely or by connecting it to base 1. See *Fig. 6A*. The difference in circuit operation between these two connections is insignificant. By either method, only one potential is connected to the base region, and this constitutes triode operation. With base 2 open the total leakage of previous stages plus its own is amplified by the current gain of the output transistor. This amplified leakage current represents the minimum controllable output current. If the load current is reduced below this value the output voltage will rise resulting in a loss of regulation. (Control Region 1, *Fig. 7.*)

Suppose the transistors were mounted on a dissipator whose temperature was maintained at 25°C. It is shown in *Fig. 7* that the leakage current would have a maximum value of 300 *ma* when the input voltage is 32 volts. In this case, a bleeder of less than 74 ohms and a power capacity of 6.6 watts is adequate to provide good regulation. However, if the load had consumed 3 amperes from a 32-volt supply just prior to its removal, the power dissipated in the transistor would be at least 30 watts. At $\theta = 1°C/W$, the junction will not be at 25°C but at 55°C. At this temperature, the system leakage current is 3 amperes and any reduction in regulator current will cause the voltage regulation to be lost for a period sufficient for the transistor to cool to the point where the bleeder resistor can maintain regulation.

Consequently, this triode with a thermal resistance of 1°C/*W* cannot absorb this amount of power and remain a stable regulator even when the transistor case is maintained at 25°C.

The requirement for being able to remove the load or, for that matter, even to cause considerable variation in the load, imposes the greatest limitation on this type of circuitry. These considerations govern the size of bleeder required. A heavy bleeder wastes power, reduces efficiency, limits the useful output current, and usually generates heat where it is undesirable.

Suppose we are willing to use a 1-ampere bleeder resistance in order to stabilize the regulator for load removal. Using a triode as the power regulator, it is shown in *Fig. 7* that the junction temperature must be kept under 40°C to limit the total leakage current to the bleeder to 1 ampere. If the power released by the bleeder does not heat the transistor, which can be kept to 25°C, the circuit will provide good regulation as long as the output transistor dissipates no more than 15 watts.

Since the output voltage is held at 22 volts and the supply can be kept as high as 32 volts, the thermal consideration will limit the regulated current to 1.5 amperes. With 1 ampere for the bleed, there is only ½ ampere left for useful load.

In a practical circuit, these conditions are aggravated because the transistor cannot be kept to a 25°C

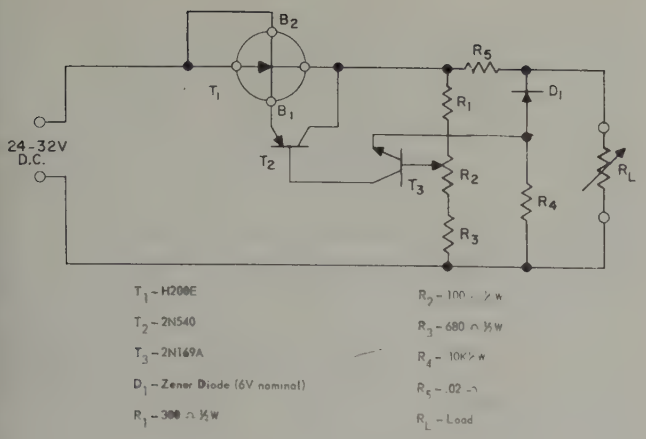



**Fig. 5—Direct coupled voltage regulator.**

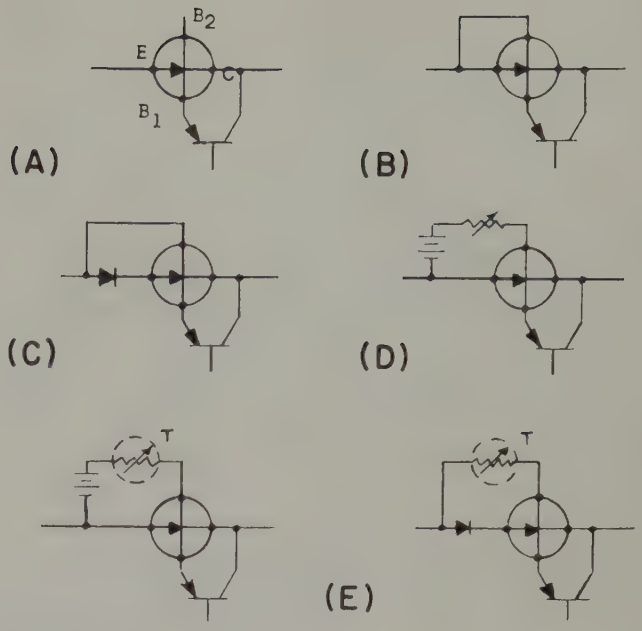



**Fig. 6—(a) Triode operation of tetrode transistor achieved by keeping base 2 open (or connecting it to base 1.)**
**(b) Simple tetrode configuration where base 2 is returned to the emitter.**
**(c) Diode inserted in emitter lead provides a small back bias on base 2.**
**(d) Separate battery combats amplified leakages from previous stages and biases the output transistor to its lowest leakage.**
**(e) Use of temperature sensitive elements provides additional temperature compensation.**

temperature. The best that can be done is to attach it to the chassis which will always be warmer than surrounding temperatures. When the cooling is hindered by a bleeder which may have a steady dissipation as high as 22 watts, it is easy to understand why this type of regulator is difficult to design.

By using the simplest tetrode configuration (*Fig. 6B*), that of returning base 2 to the emitter, the leakage of the output stage is reduced and a small input threshold is created which nullifies the amplified leakage currents of the preceding stages. As the temperature increases, the amplified leakage of the initial stages will begin to overcome the input threshold value and become amplified by the output stages. It can be seen from *Fig. 7* that the temperature for stable operation of this tetrode circuit is increased about 10°C over the case for a triode.

The shorting of base 2 to the emitter provides a "nonamplifying" path for the leakage current of the output transistor and an input threshold for the leakage current of the previous stages. Higher temperature operation is possible before loss of regulation occurs. (Control Regions 1 and 2, *Fig. 7.*)

Inserting a diode in the emitter lead in its forward direction causes a small voltage drop that may be used effectively to provide a small back bias on base 2 (see *Fig. 6C*). The performance for the particular diode used allows stable operation for another 10°C. (Control Regions, 1, 2 and 3, *Fig. 7.*)

Use of a separate battery (*Fig. 6D*) provides a larger input threshold to combat the amplified leakage of previous stages, and biases the output transistor to its lowest leakage. This configuration is unconditionally stable to junction temperatures of 65°C. At higher temperatures a bleed resistor is necessary to provide regulation if the load is opened. A 110-ohm, 5-watt resistor will provide sufficient bleed power to stabilize the regulator at a junction temperature of 85°C. Thus, the regulator could handle permanently the full 3 amperes at an input level of 32 volts and chassis tem-

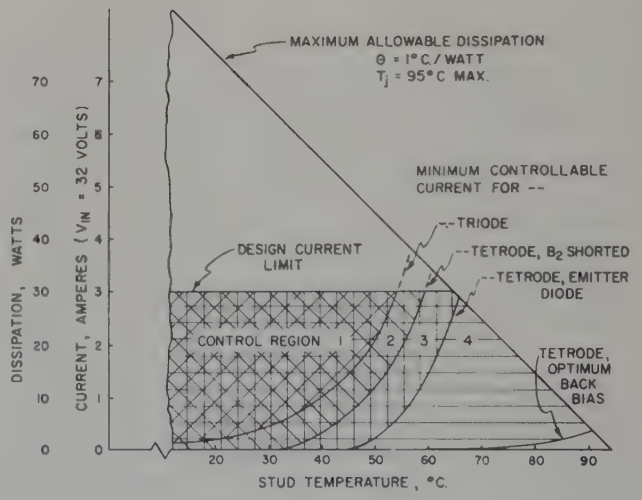

MAXIMUM ALLOWABLE DISSIPATION
θ = 1°C/WATT
Tj = 95°C MAX.
MINIMUM CONTROLLABLE CURRENT FOR --
--TRIODE
--TETRODE, B2 SHORTED
--TETRODE, EMITTER DIODE
DESIGN CURRENT LIMIT
CONTROL REGION 1 2 3 4
TETRODE, OPTIMUM BACK BIAS
DISSIPATION, WATTS
CURRENT, AMPERES (VIN = 32 VOLTS)
STUD TEMPERATURE, °C.
0 10 20 30 40 50 60 70
0 1 2 3 4 5 6 7
20 30 40 50 60 70 80 90

**Fig. 7—Perfomance characteristics, showing typical control ranges as bounded by the minimum controllable current, maximum design current limit, and allowable power dissipation for each of the tetrode base 2 configurations shown in Fig. 6.**

perature of 55°C. At higher chassis temperatures, the regulation may be lost upon opening the load if the regulator had been working to its power capacity previously.

If a 55-ohm, 10-watt bleeder were used, the regulator would be stable under conditions of load removal up to junction temperatures of 95°C. At a full load of 3 amperes and high input voltage of 32 volts, the chassis temperature can be as high as 65°C.

At a chassis temperature of 85°C the current must be restricted to 1.5 amperes, or the input supply to voltages less than 27 volts, or the junction temperature may be exceeded. (Control Regions 1, 2, 3 and 4, *Fig. 7.*)

Additional temperature compensation may be realized by means of thermistors or other temperature-sensitive elements as in *Fig. 6E,* which shows a more elegant method of providing the necessary tetrode biases using thermistors attached to the chassis. In this way, the back bias increases with temperature.

This one circuit illustration is an example of the increased stability of a power tetrode over a power triode. The tetrode is well suited for direct-coupled circuitry because it removes the leakage current from the signal path and, therefore, the leakage is not amplified. The tetrode makes it possible to realize the current gain of the common emitter configuration with the leakage and stability of the common base configuration.

# Transistor Resistor Logic

Q. W. SIMKINS*

**Transistor resistor logic offers considerable advantage over most competing logic circuits in reliability and economy and should be considered for moderate speed applications. In this article the procedures for optimizing a design and determining design limitations using a particular transistor are outlined. While results in the form of design capability are best obtained with an automatic computer, the design procedures are relatively straightforward. It can be seen from results presented for a 2N393 transistor that a TRL building block circuit with a fan-in of 5, a fan-out of 5 and a maximum signal propagation delay per stage of 0.5 microsecond is designable. The results are experimentally verified.**

THE SELECTION of logical circuits for a large-scale data processing system involves the consideration of many factors. Depending on the particular application, the relative importance of these factors will vary, but to some extent at least, the following considerations generally apply: *Reliability, Designability, Economy* and *Operational Requirements* imposed by the system. In many instances the operational requirements can be met using any of several circuit forms making the circuit choice a function of system reliability, designability and economy. The circuit designer is often faced, at this point, with a choice between a relatively complex circuit form with which the device requirements can be made more lenient and a relatively simple circuit form with which a somewhat higher performance device is required.

Considering the rapid advances in semiconductor technology and the objectives outlined above, the latter approach is attractive. A particularly simple, reliable and economic circuit form, Transistor Resistor Logic, or more simply, *TRL*, is the subject of this article. In particular the system operational requirements imposed on the logic circuits are related through an experimentally verified analysis and the limiting performance characteristics of *TRL* using several transistor types are determined.

Transistor Resistor Logic which utilizes a resistor gate and an inverting transistor amplifier has been used in several digital systems, such as the Westinghouse Nordic Computers[1] and is fairly well known. However, a brief description of the *TRL* circuit and its application to digital data processors is included here for completeness. The building block parameters are then discussed and they are related by means of an approximate analysis intended to give some insight to the design problem. After the presentation of some typical results in the form of design capability curves there follows a detailed circuit design procedure or analysis which relates all the circuit parameters in-

*Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.

[1]W. D. Rowe "The Transistor NOR Circuit" 1957, IRE WESCON Convention Record Pt. 4, pp. 231-245.

cluding speed. Finally the results are discussed and conclusions drawn.

In *Fig. 1* the basic *TRL* building block and flip-flop are shown. Although *n-p-n* transistors are shown in the figure either *p-n-p* or *n-p-n* devices can be used with appropriate polarity voltage supplies. The building block consists of a resistor gate followed by an inverting transistor amplifier. The gate is an *"or"* gate to off-ground signals and an *"and"* gate to ground signals. Any combinational logic circuit can be implemented using these simple building blocks. The flip-flop consists of two building blocks in a re-entrant connection.

Several characteristics or system operation parameters of these building blocks may be illustrated in this figure. The number of resistive legs on the input gate is referred to as the *"fan-in"* and the number of *TRL* inputs which can be driven from the collector node is called the *"fan-out."* Another important systems parameter of the building block is the speed at which signals are propagated through a logical network. The signal propagation time through a building block circuit determines the operating speed of the data processor and consequently is of major systems interest. Still another characteristic of importance, particularly when high reliability is of major interest, is the margin against false operation due to inductively or capacitively induced signals provided by the resistive interstage network. An additional system parameter might be the operational temperature range. This parameter has not been considered in the analysis which follows; however, the modifications necessary are fairly simple and apparent.

In *Fig. 2* the circuit to be analyzed is shown. It is assumed here that the transistor at the right is to be turned on by current supplied from the collector node shown at the left. The relationships are derived considering worst circuit conditions. Resistor and power supply tolerances of 5% (which are well within the end of life characteristics of the devices used) are assumed in the analysis leading to the results shown in *Fig. 3*. The inequalities at the bottom of *Fig. 2* indicate that the minimum value of the transistor current gain (in saturation) must be greater than the maximum circuit current gain required. The latter expression is factored to provide some insight to the problem.

The first factor, $\frac{I_{6\ max}}{I_{1\ min}}$, in the expression for the maximum circuit current gain is the ratio of the current supplied to the collector node of an *on* transistor to that supplied to the collector node of an *off* transistor and is designated the current source factor. It is a measure of the constancy of current supplied to the collector node and depends on the maximum amplitude of the collector voltage swing from the *on* to *off* state relative to the value of the supply voltage.

The second factor, $\frac{I_{1\ min}}{I_{2\ min}}$, is very nearly equal to

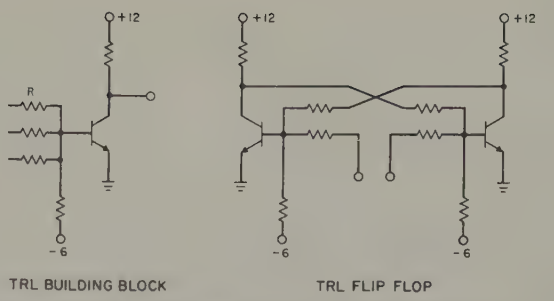
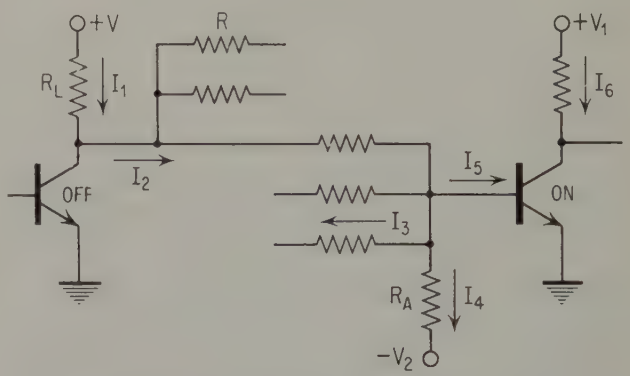



**Fig. 1—*TRL* building block and flip-flop.**




$$\beta_{S\ MIN} \geqq \frac{I_{6\ MAX}}{I_{5\ MIN}} = \left(\frac{I_{6\ MAX}}{I_{1\ MIN}}\right) \times \left(\frac{I_{1\ MIN}}{I_{2\ MIN}}\right) \times \left(\frac{I_{2\ MIN}}{I_{5\ MIN}}\right)$$

$$\beta_{S\ MIN} \cong \left(\begin{array}{c}\text{CURRENT SOURCE}\\ \text{FACTOR}\end{array}\right) \times N_0 \times \left(\frac{I_{B_1} + I_{B_2}}{I_{B_1}}\right)$$

**Fig. 2—*TRL* circuit interconnections.**

the building block fan-out $N_o$. It might be noted that the base-robbing problem of *DCTL*[2] is avoided in *TRL* by the inclusion of the series gating resistors.

The third factor, $\frac{I_{2\ min}}{I_{5\ min}}$, in the expression for circuit current gain can be related approximately to the forward and reverse base currents $I_{B1}$ and $I_{B2}$ supplied to the *on* transistor. $I_{5\ min}$ is, of course, just $I_{B1\ min}$. $I_{2\ min}$ is equal to the sum of $I_5$, $I_4$ and $I_3$ under the appropriate tolerance conditions. Since the value of the internal base resistance of the transistor is 50 to 100 times smaller than the circuit resistance values, the base voltage during the turn-off transient will be nearly equal to the *on* base voltage and thus $I_3$ and $I_4$ will be nearly equal to the transient reverse base current, $I_{B2}$. Thus, the last term can be related to forward and reverse base currents and in turn to the circuit speed.

Maximum turn-on time results from minimum base current drive ($I_{B1}$) while maximum turn-off time results from maximum forward base current $I_{B1}$ and

[2]J. R. Harris—"Direct Coupled Transistor Logic Circuitry"—IRE Transactions on Electronic Computers, March 1958.

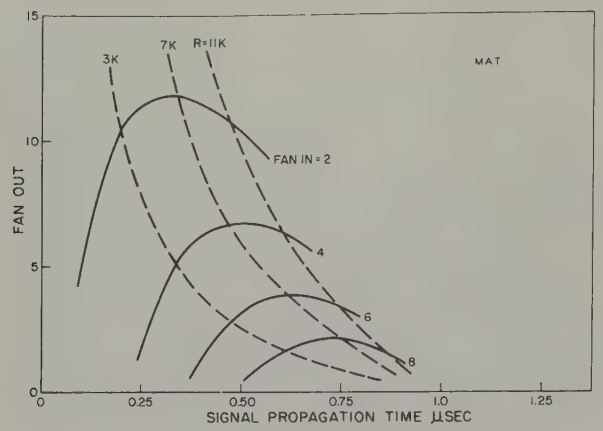



**Fig. 3—Design capability curves.**

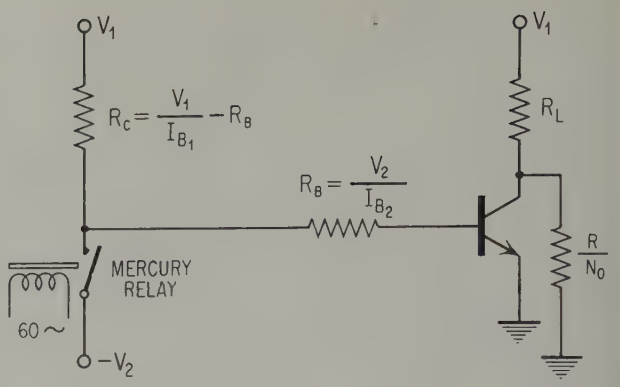



**Fig. 4—Transistor transient test circuit.**

minimum reverse base current $I_{B2}$. The slowest signal propagation speed results, therefore, when the transistors turning *on* have minimum drive and the transistors turning *off* have the maximum drive before the signal transient. This maximum base drive, which has a very substantial effect on the signal propagation time, is a function of the circuit fan-in.

We have now shown in an approximate way the relationship of circuit fan-in, fan-out and signal propagation time. The final restraint applied in the calculation of the design capability curves is the provision of at least a 150 millivolt margin against false operation of an *off* transistor through the design of the resistive interstage.

In *Fig. 3* typical results of the analysis to follow are shown in the form of design capability curves of a *TRL* building block utilizing a 2N393, a *p-n-p* germanium transistor. The 2N393 has a *d-c* current gain of 30 or more and an alpha cutoff frequency of about 50 *mc*. From these curves a *TRL* building block can be designed and its system operational parameters under worst circuit conditions determined. For example, a building block with a maximum fan-in of 5, fan-out of 5, and maximum signal propagation time of 0.5 microsecond can be designed. Preliminary logical design work indicates that such a building block will satisfy a large percentage (80-90%) of many system needs. Shown in dashed lines are the corresponding values of the coupling resistor which in this case is about 5K. From these curves the maximum fan-in and fan-out capabilities independent of speed are readily seen.

### Circuit Analysis

The curves of *Fig. 3* and the subsequent design capability curves are based on: (1) Two *TRL* circuit inequalities which relate *d-c* conditions, (2) The minimum forward base current during the turn-on transient, (3) The maximum forward base current immediately prior to the turn-off transient, (4) The minimum reverse base current during the turn-off transient, (5) The experimentally determined speed relationships for a minimum specification unit, and (6) An approximate equation relating the signal propagation delay of a transistor logic stage to the turn-on and turn-off transients.

An analysis of the first of the two *d-c* circuit inequalities, shows the minimum conditions for turn-on of a *TRL* circuit with maximum fan-in, $N_i$, driven by a similar *TRL* circuit with maximum fan-out, $N_o$. Worst circuit conditions assumed include the most adverse combination of resistor and power supply tolerances and the most adverse transistor parameters allowable under the specification. In a slightly simplified form, these inequalities are,

1. "ON" Condition

$$\frac{V_{1\,max}}{\beta_{min}\,R_{L\,min}} \leqq \frac{V_{1\,min}}{N_o R_{L\,max} + R_{min}}\left(\frac{R_{min}}{R_{max}}\right) - \frac{(V_{be\,max} - V_{ce\,min})}{R_{min}}(N_i - 1) - \frac{V_{2\,max} + V_{be\,max}}{R_{A\,min}} \quad (1)$$

2. "OFF" Condition

$$V_{BO\,max} - V_N \geqq V_{ce\,max} - \frac{(V_{2\,min} + V_{ce\,max})}{R_{min} + N_i R_{A\,max}} R_{min} \quad (2)$$

$V_1$ = Collector Supply Voltage
$V_2$ = Bias Supply Voltage
$R$ = Gating Resistor
$R_L$ = Collector Supply Resistor
$R_A$ = Bias Supply Resistor
} See Figure 2
$N_o$ = Fan-out
$N_i$ = Fan-in
$\beta$ = Transistor Saturated Current Gain
$V_{be}$ = Base "ON" Voltage
$V_{BO}$ = Base "OFF" Voltage
$V_{ce}$ = Collector "ON" Voltage
$V_N$ = Noise Margin

Relating this inequality to the circuit of *Fig. 2*, the first term is $I_{6\,max}$ divided by the minimum circuit gain, the resulting current being $I_{5\,min}$. The second term is the minimum value of $I_2$ and the third and fourth terms are maximum values of $I_3$ and $I_4$, respectively.

The *off* condition inequality states that under worst circuit conditions an *off* transistor must be held *off* by

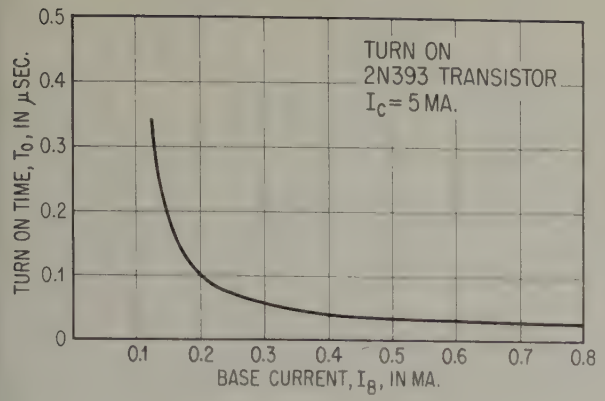



**Fig. 5—Turn "ON" Time, $T_O$, vs. Base Current, $I_{B1}$, of a 2N393 transistor.**

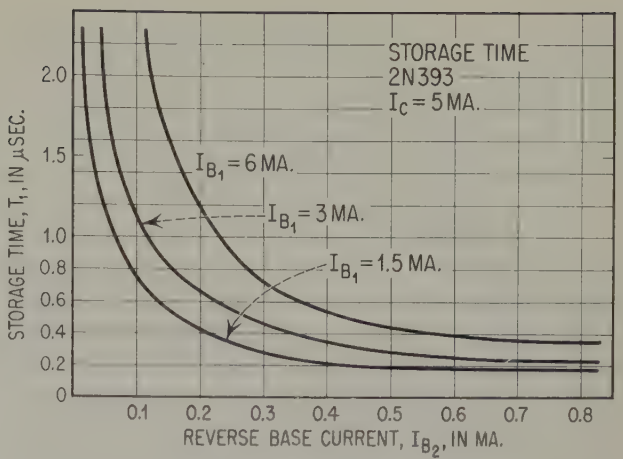



**Fig. 6—Storage Time, $T_1$, vs. Reverse Base Current, $I_{B2}$, of a 2N393 transistor.**

the voltage divider between the bias supply voltage $V_2$ and the on collector voltage, $V_{ce}$, of the driving *TRL* circuits. A minimum noise margin, $V_n$, is specified to prevent spurious operation due to capacitively or inductively coupled noise or crosstalk signals. In a practical system these unwanted signals must be minimized through careful packaging arrangements, low impedance levels, short lead lengths and shielding from high energy external signals where necessary. With such equipment design precautions and with a moderate speed system, such as that indicated by the design curves of *Fig. 3*, a noise margin of 150 millivolts is found to be adequate.

The base currents which affect the transient performance of the *TRL* circuit are related to the circuit parameters by the following equations.

Turn "ON" forward base current

$$I_{B1\,min} = \frac{V_{1\,min}}{N_o R_{L\,max} + R_{min}} \left(\frac{R_{min}}{R_{max}}\right) - \frac{(V_{be\,max} - V_{ce\,min})}{R_{min}} (N_i - I) - \frac{V_{2\,max} + V_{be\,max}}{R_{A\,min}} \qquad (3)$$

Turn "OFF"

Forward base current prior to transient

$$I_{B1\,max} = \frac{V_{1\,max}}{N_o R_{L\,min} + R_{max}} \left(\frac{R_{max}}{R_{min}}\right) N_i - \frac{(V_{2\,min} + V_{be\,min})}{R_{A\,max}} \qquad (4)$$

Reverse base current during transient

$$I_{B2\,min} = \frac{V_{2\,min} + V_{be\,min}}{R_{A\,max}} + \frac{(V_{be\,min} - V_{ce\,max})}{R_{max}} N_i \qquad (5)$$

Other circuit conditions which determine the speed of the turn-on and turn-off transients are the collector current and the effective collector load impedance. The collector current is approximately equal to the collector supply voltage divided by the load resistor $\left(I_c = \frac{V_1}{R_L}\right)$ The effective load impedance is nearly equal to the parallel combination of the load resistor, $R_L$, and the $N_o$ coupling resistors.

The transistor rise, storage and fall times ($T_o$, $T_1$ and $T_2$, respectively) are related to the base and collector currents and the transistor parameters as shown by Ebers and Moll[3]. While these analytical relationships agree reasonably well with experimental data, it is perhaps easiest and most effective to use the experimental data directly. These data may be readily acquired using the test circuit of *Fig. 4* or any of several similar configurations. The maximum anticipated circuit capacity should be included in this test circuit. Typical curves thus obtained are shown in *Figs. 5, 6* and *7*.

With the foregoing data, it is possible to determine the minimum transient response for any of several

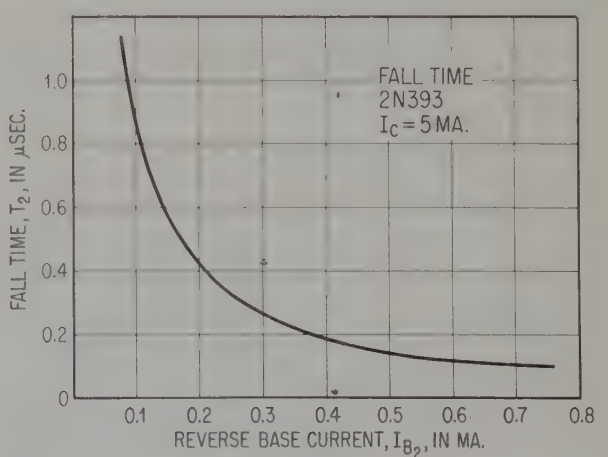



**Fig. 7.—Turn "OFF" Time, $T_2$, vs. Reverse Base Current, $I_{B2}$, of a 2N393 transistor.**

[3]J. J. Ebers and J. L. Moll, "Large-Signal Behavior of Junction Transistors". Proc. IRE, Vol. 42, pp. 1761-1772, December 1954.

*TRL* circuit designs satisfying the inequalities of Equations (1) and (2). It has been shown that over a limited range of values the average signal propagation delay per stage, $T$, of an overdriven transistor amplifier is given approximately by

$$T = \frac{T_0}{4} + \frac{T_1}{2} + \frac{T_2}{4}.$$

The optimum circuit design for a given set of circuit and device parameters is then obtained by selecting a circuit design satisfying the required inequalities in which the average circuit delay as calculated from the above formulae is minimized. This optimization procedure can, of course, be a rather formidable task and is best accomplished by a high speed computer. It has generally been found with germanium alloy transistors that an optimum design results from equating the two sides of the *on* condition inequality. The optimum is also usually closely approached when the ratio $\frac{I_{B1\,max}}{I_{B2\,min}}$ is minimized. This is not surprising in view of the Ebers-Moll equations for storage time which often predominates in the delay equation.

Several *TRL* circuits designed by the above procedure have been experimentally tested and found to agree rather well with the predicted results. The predicted speed is, of course, always pessimistic since all worst circuit conditions are assumed. For example, the average signal propagation delay in an experimental model containing about 150 *TRL* circuits designed from the curves of *Fig. 3* ($N_o = 5$, $N_i = 5$, $T = 0.5$ μsec.) is only about 0.2 microseconds. This discrepancy is due to the severity of the worst circuit condition assumptions, particularly the turn-off after maximum saturation condition. It is possible in many cases to take advantage of this somewhat higher speed in the design of the data processing system. This is particularly true when values of fan-in lower than the maximum prescribed are used, or when there are known restraints on the input variables. This same experimental model has also verified the claimed insensitivity to false operation.

One of the characteristics of the 2N393 which makes it particularly attractive in this application is its high current gain. The importance of current gain is illustrated in *Fig. 8* in which the *TRL* design capability curves using transistors with saturation current gains of 30 and 15 are compared. It is evident that substantially more design flexibility is afforded by the higher gain transistor both in speed, fan-out and fan-in.

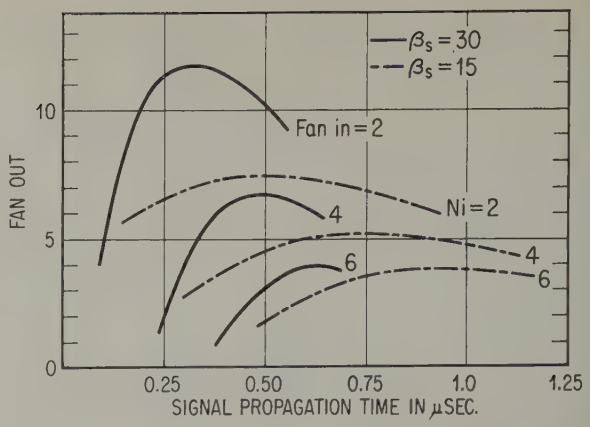



**Fig. 8—Comparison of design capability curves of transistors with gains of 30 and 15.**

## Summary

Within the design capabilities outlined Transistor Resistor Logic can be used as a reliable and economical digital system building block. Although *TRL* is not in the same speed range with some other logic circuits, it does permit circuit operation with maximum propagation times of 0.25 μsec. or less with presently available transistors, a speed which is adequate for many data processing applications. In such applications the high degree of reliability and economy afforded by the use of a fifteen cent resistor as the gating element makes *TRL* very attractive. With the rapid growth of semiconductor technology continually making available still higher performance devices, this simple circuit approach to the implementation of the logical circuits in large scale data processing systems should find wide applications.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# Marketing and Production Trends in the Semiconductor Industry

Part 4

H. E. MARROWS*

ANY NEW PRODUCT to be successful must have a combination of attributes which appeals to many individuals. In formulating this combination, however, the marketing expert inevitably faces the most difficult task of weighing cost and price against other qualities and functions the product may have. The question that always plagues him is: "Can high cost and price be overcome by needs, whims or conditions of service?"

### Hearing Aids

It was obvious to the early transistor marketing specialist that initial high prices to be charged for the new hearing aids with transistors would be offset to a great extent by reduction in size of the device as well as a saving in battery power. The reduction in size was to overcome one of the great obstacles to selling hearing aids—vanity. Since those early days of the transistor, hearing aids have come a long way in design as can be seen in *Figs. 1* and *2*. *Fig. 3* is a representative schematic of hearing aids on the market today.

At this point the hearing aid industry in the United States has been completely converted to transistors. Several transistor manufacturers make special small size, low noise units especially for the trade. Most of the units use three or four transistors, although some use as many as five. Of course, the new binaural type would use double the number of a single channel.

It is estimated that the hearing aid manufacturers have used over one million transistors a year, but the total has been getting larger for the past few years. There is little doubt that while growth in this field appears to be limited by the still present reluctance of many individuals to use hearing aids, there are other associated products which the hearing aid manufacturers seem to have ignored. For example, the author has had many inquiries from individuals looking for a tiny amplifier which could amplify a weak voice—to be used on their person. Such a personal device, not offered commercially as far as the author knows, certainly belongs to the hearing aid manufacturer. A list of most of the hearing aid manufacturers in the United States is shown in Table I.

### Portables and Other Entertainment Applications

The next large use of transistors, it appears, will be in home radios and associated entertainment applications, such as preamplifiers, audio amplifiers, phonographs and tape recorders. The last two applications have come along slowly, a principal reason being, according to the manufacturers, a lack of low cost, quiet motors adequate for the purpose. Trav-Ler now has a 4-transistor 45 *rpm* phonograph while Broadcast Equipment Specialties, which makes the Tapak Newscaster-Duplex tape recorder is planning to have an all-transistor recorder shortly.

Use of transistors for portables should just about preempt tubes by 1960. The present use has been extended to almost every major manufacturer of radios. A list of companies making portable transistor radios, preamplifiers, phonographs and tape recorders is shown in Table II.

A recent study of about 100 basic all-transistor portable radio models made commercially in the U. S., not

**Fig. 1—Concealed hearing aids.** ***(Nichols and Clark, Inc.)***

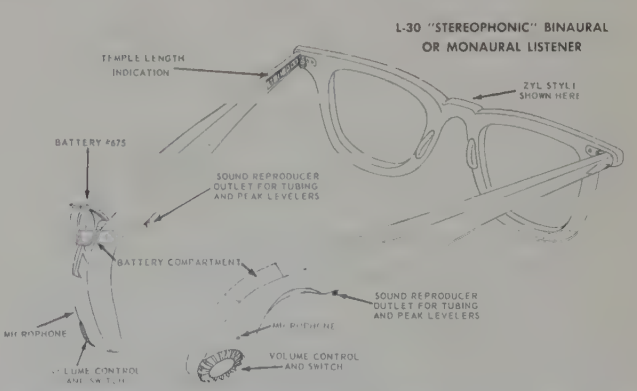
L-30 "STEREOPHONIC" BINAURAL OR MONAURAL LISTENER
TEMPLE LENGTH INDICATION
ZYL STYLI SHOWN HERE
BATTERY #675
SOUND REPRODUCER OUTLET FOR TUBING AND PEAK LEVELERS
BATTERY COMPARTMENT
SOUND REPRODUCER OUTLET FOR TUBING AND PEAK LEVELERS
VOLUME CONTROL AND SWITCH

**Fig. 2—Binaural or Monaural hearing aid built into frame of eye-glasses.** ***(Otarion, Inc.)***

* Author: "Transistor Engineering Reference Handbook," published by John F. Rider.

including kits, shows a wide variety of transistors and circuit configurations. *Fig. 4* shows the pattern of distribution of these all-transistor radios by number of transistors per set. A number of receivers using two or three transistors have been announced but these do not appear to have made much progress in the market. It is believed by some marketing men that this field of tiny devices using two or three transistors has a good potential for the future in a variety of uses, but it will be difficult to overcome some preconceived notions that these units can only be toys. As paging receivers gain acceptance, it is possible that this field of two and three transistor units can become greater than the present portable radio market.

The wide variety of transistor code numbers used in portable radios makes it almost impossible to show any pattern of standardization or trend. Although most of the receivers use a 1N295 or 1N87 diode as a detector, the transistor types are scattered throughout the EIA spectrum.

A study of the *if* amplifier stages really becomes confusing. Over thirty different codes are specified for first *if* stages and almost the same number appears in second *if* stages.

The same pattern of diversity appears in the audio driver and output transistors. Although some are used in both the driver and output stage, such as the 2N35, 2N109, 2N185, 2N217, 2N229, 2N291, 2N306, 2N383, 2N406, 2N407, 2N408 and the GT20.

This great variety of transistor codes in the output stage is, of course, reflected in a fairly large range of power outputs, which runs from 25 *mw* to 500 *mw* in radios having from 4 to 9 transistors.

Despite this great variety of transistors, a real eye opener occurs in the Regency 7 transistor set which has a 2N229 in each of the seven stages.

Prices of the transistor portables are gradually coming down toward the level of the better made tube types. Their main marketing advantages are in size and battery economies. Other interesting innovations have appeared, one of which is the return to the reflex circuit, wherein one transistor acts as the *if* as well as the audio amplifier. An example of this type of circuit is shown in *Fig. 5*. Another innovation is the incorporation of a charging circuit in some of the portables by which the battery of the radio can be charged from a home line.

Transistor radios came in significantly in 1955, and in 1956 almost a million were made. In 1957 it is estimated that almost two million were manufactured, with prospects that 1958 would double the previous year's figure. On top of this, large imports from Japan (in the order of 500,000) will cover the country adequately. Some estimates made report that at present 50% of transistor portables being sold in the U. S. are of Japanese manufacture.

### Console and Table Models

The immediate future for transistor radios appears

**TABLE I**

**Hearing Aid Manufacturers**

| | |
|---|---|
| Acousticon | Nichols & Clark, Inc. (Unex Laboratories) |
| Audivox | Otarion Listener Corporation |
| Aurex Corporation | Paravox, Inc. |
| Beltone Hearing Aid Co. | Prescription Hearing Aid Company, Inc. |
| Dahlberg Company | Sonotone Corporation |
| Gem Ear Phone Company | Telex, Inc. |
| Hal-Hen Company | Zenith Radio Corporation |
| Maico Company, Inc. | |
| Microtone Corporation | |
| E. A. Myers & Sons, Inc. | |

**TABLE II**

**Manufacturers of Radios, Preamps, Phonos and Tape Recorders**

| | |
|---|---|
| Admiral Corporation | sion of Hoffman Electronics Corporation |
| Arvin Industries, Inc., Radio & Television Div. | The Magnavox Company |
| Automatic Radio Mfg. Co., Inc. | Motorola, Inc. |
| Broadcast Equipment Specialties Corp. | Packard Bell |
| Bulova Watch Co. | Philco Corporation |
| Columbia Records, Div. of Columbia Broadcasting System, Inc. | Radio Corporation of America |
| Delco Radio Div., General Motors Corp. | Regency Div., I.D.E.A., Inc. |
| DeWald Radio & Television Corp. | Roland Radio Corp. |
| Emerson Radio & Phonograph Corp. | Sylvania Electric Products, Inc. |
| Fisher Radio Corp. | Trav-Ler Radio Corp. |
| General Electric Company | Warwick Manufacturing Corporation |
| Hoffman Radio, A Divi- | Westinghouse Electric Corp. |
| | Wilcox-Gay Corporation |
| | Zenith Radio Corporation |

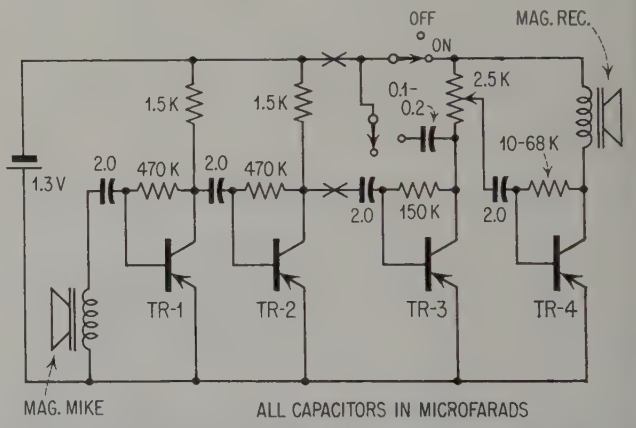


**Fig. 3—Representative schematic of current hearing aid amplifiers. *(Nichols and Clark, Inc., Unex Visionear)***

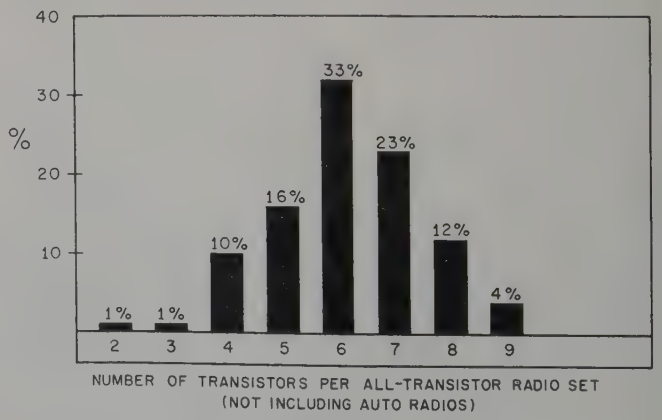


**Fig. 4—Distribution of portable transistor receivers by the number of transistors per set.**

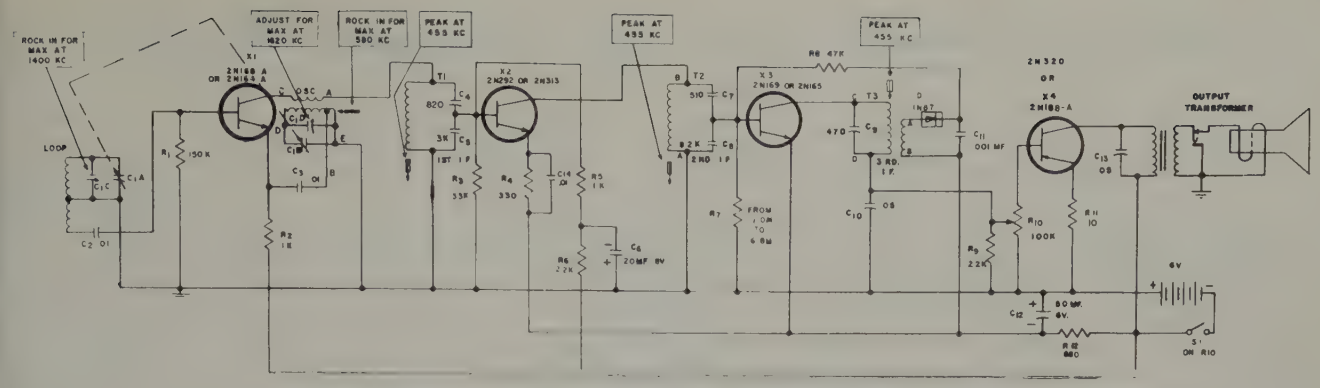


**Fig. 5—Example of a receiver using reflex circuitry. (G.E.)**

bright, for there is a definite feeling by the buying public that transistors have a number of advantages over their tube rivals. It appears that the next large market to be developed (outside of automobile radios) will be the home radio console or home table models and associated high fidelity audio equipment. With the appearance of adequate high power and *fm* broadcast band transistors, the road seems to be well paved for this advance. Again, higher costs will be the great dilemma facing the marketing expert, but other advantages if properly pointed out in merchandising should overcome this resistance. The surprising interest in all-band transistor receivers by the consumer is a good indication of the acceptance of these higher priced units.

Among the companies which are making the multiband receivers are: Philco Corporation, The Magnavox Company, Radio Corporation of America, Regency Division of I.D.E.A., Inc., Zenith Radio Corporation and Hallicrafters Co. These units go to about 22 *mc*.

Approaches to the console type radio have been made by several companies. Trav-Ler Radio Corporation has introduced what the company calls a "Porta-Console" while Arvin Industries has designed one of its portables, Model 9562 to be also used as a console with appropriate wrought iron legs. Other companies showing table type models are: Admiral Corporation, Philco Corporation, RCA, Westinghouse and others.

### Kits

Another aspect of the transistor business which may become important is kit manufacturing. This practice, with some notable exceptions, has not been successful in the electron tube industry. One reason for this is that the tube circuits generally required high voltages that were obtained from the line current. The use of transistors makes a kit builder feel safer. Also, of course, the shipment of tubes is more apt to result in damages.

Several companies have made large inroads in the kit field. Among these are the Heath Company, Lafayette Radio, Tran-Kit Electronics Co., Inc., Allied Radio, Superex Electronics Corp. and Arkay.

### Automobile Radios

It is evident that transistors have made a large impact on automobile radios, although exact figures are difficult to obtain. Most of the auto radios are hybrid types, employing transistors only in the output stage. However, within a year or two there is no doubt that the transistor will take over completely.

An elaborate circuit used by Delco contains 13 transistors and in line with usual design practices for automobile radios has a separate *rf* amplifier as well as a separate oscillator. Switching of stations is also accomplished through transistor circuits and the circuit would be suitable for other applications. Additional semiconductor products such as three diodes and a thermistor give the unit excellent stability and reliability.

Another innovation that has caught the fancy of customers is the General Motors' portable auto radios which appear in Oldsmobile and Pontiac cars. Versatility of transistors and ingenius automatic switching circuits make it possible to remove the radio from the car for use as a small portable unit. In the car, the radio is a 10-transistor unit, but when taken out becomes a 9-transistor portable with a 3-inch speaker and operates on a 6-volt battery supply.

### Summary

Further marketing innovations are: two speakers, clock radios, use of solar batteries and two earphone jacks in one set. One radio (Zenith-Model 760) incorporates a low frequency band 150 *kc* to 400 *kc*.

The growing market of transistor radios has probably been the greatest spur to transistor manufacturing outside of military requirements. Certainly, the radio advancements have been more orderly and have afforded extensive field use. Even greater strides in the manufacture of transistors are being made today to extend their use to home radios, high fidelity audio amplifier equipment and, eventually, to home television receivers. When a device reaches into these fields, it has indeed become a factor in the American economy.

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| On Kinetics of Phototriodes | Soviet Physics Technical Physics (trans) 6/58 | Results of the determination of the time constant of phototriodes are given, followed by a consideration of relaxation curves for phototriodes. | S. M. Ryvkin<br>N. B. Strokan |
| Neutron Bombardment Effects in Semiconductors | U.S. Gov't Research Reports WAPD-STR (Ph)-83-LC 10/17/58 | | W. Russ |
| Accurate Transistorized Multiplier-Divider | U.S. Gov't Research Reports PB 133363-LC 10/17/58 | Description of an analog device that can simultaneously perform the mathematical operations of multiplication and division. | R. W. Hoedemaker |

# CHARACTERISTICS CHARTS OF NEW DIODES and RECTIFIERS

**ANNOUNCED BETWEEN DEC. 1, 1958 and JAN. 31, 1959 ONLY**

**Charts of Silicon Zener of Avalanche Diodes, Switching Diodes, Voltage Variable Capacitor Diodes, and other types of diodes will be published in the May issue of SCP.**

## MANUFACTURERS

| | |
|---|---|
| AMP— | Amperex Electronic Corp. |
| AUD— | Audio Devices, Inc. |
| BEN— | Bendix Aviation Corp. |
| BER— | Berkshire Labs |
| BOG— | Bogue Electric Mfg. Co. |
| BOM— | Bomac Labs |
| BRA— | Bradley Labs |
| BTHB— | British Thomson-Houston Export Co., Ltd. |
| CBS— | CBS-Hytron |
| COL— | Columbus Electronics Corp. |
| CTP— | Clevite Transistor Products, Inc. |
| CSF— | Compagnie Generale de T.S.F. |
| EEVB— | English Electric Valve Co., Ltd. |
| ERI— | Erie Resistor Corp. |
| FAN— | Fansteel Metallurgical Corp. |
| FERB— | Ferranti Ltd. |
| GAH— | Gahagan, Inc. |
| GECB— | General Electric Co., Ltd. |
| GE— | General Electric Company, Semiconductor Div. |
| GIC— | General Instrument Corp. |
| GTC— | General Transistor Corp. |
| HSD— | Hoffman Semiconductor Division |
| HUG— | Hughes Products Division |
| IFHS— | Institutet for Halvledarforskning |
| INRC— | International Rectifier Corp. |
| IRC— | International Resistance Co. |
| ITT— | International Tel. & Tel. Corp. |
| KEM— | Kemtron Electron Products, Inc. |
| LCTF— | Laboratoire Central de Telecommunications |
| MAL— | P. R. Mallory & Co., Inc. |
| MIC— | Microwave Associates, Inc. |
| MOT— | Motorola, Inc. |
| MUL— | Mullard, Ltd. |
| NAE— | North American Electronics |
| NPC— | Nucleonic Products Co., Inc. |
| OHM— | Ohmite Manufacturing Co. |
| PHI— | Philco Corp. Lansdale Tube Company |
| PSI— | Pacific Semiconductors, Inc. |
| QSC— | Qutronic Semiconductor Corp. |
| RAY— | Raytheon Manufacturing Company |
| RCA— | Radio Corporation of America, Semiconductor Div. |
| RRC— | Radio Receptor Co., Inc. |
| SAR— | Sarkes Tarzian, Inc., Rectifier Division |
| SEM— | Semi-Elements Inc. |
| SIE— | Siemens & Halske Aktiengesellschaft |
| SSD— | Sperry Semiconductor Division |
| STC— | Shockley Transistor Corp. |
| STCB— | Standard Telephone & Cables, Ltd. |
| SYL— | Sylvania Electric Products, Inc. |
| TFKG— | Telefunken, Ltd. |
| THE— | Thermosen, Inc. |
| TI— | Texas Instruments, Inc. |
| TKD— | Tekade, Nurnberg, Germany |
| TOK— | Tokyo Tsushin Kogyo, Ltd. |
| TRA— | Transitron Electronic Corp. |
| TUN— | Tung-Sol Electric, Inc. |
| TSC— | Trans-Sil Corp. |
| USD— | United States Dynamics Corp. |
| USS— | U. S. Semiconductor Products, Inc. |
| WEC— | Western Electric Co. |
| WEST— | Westinghouse Electric Corp. |

## CHARACTERISTICS CHART of DIODES and RECTIFIERS

| TYPE NO. | USE (See Code Below) | MAT | PIV (volts) | MAX. CONT. WORK. VOLT. (volts) | Min. Forward Current @ 25°C $I_f$ @ $E_f$ (mA) | (volts) | MAX. D.C. OUTPUT CURRENT[4] (amps) | @ T (°C) | MAX. FULL LOAD VOLT. DROP[4] (volts) | Max. Rev. Current $I_b$ @ $E_b$ @ T (uA) | (volts) | (°C) | MFR. (See code at start of charts) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1N1563A | 1 | S1 | 100 | | | | 1.5 | 25 | | 150(5) | | 150 | MOT |
| 1N1564A | 1 | S1 | 200 | | | | 1.5 | 25 | | 150(5) | | 150 | MOT |
| 1N1565A | 1 | S1 | 300 | | | | 1.5 | 25 | | 150(5) | | 150 | MOT |
| 1N1566A | 1 | S1 | 400 | | | | 1.5 | 25 | | 150(5) | | 150 | MOT |
| 1N1581 | 2 | S1 | 50 | | | | 3.0 | 150 | 1.5 | 500 | 50 | 150 | TRA |
| 1N1582 | 2 | S1 | 100 | | | | 3.0 | 150 | 1.5 | 500 | 100 | 150 | TRA |
| 1N1583 | 2 | S1 | 200 | | | | 3.0 | 150 | 1.5 | 500 | 200 | 150 | TRA |
| 1N1584 | 2 | S1 | 300 | | | | 3.0 | 150 | 1.5 | 500 | 300 | 150 | TRA |
| 1N1585 | 2 | S1 | 400 | | | | 3.0 | 150 | 1.5 | 500 | 400 | 150 | TRA |
| 1N1586 | 2 | S1 | 500 | | | | 3.0 | 150 | 1.5 | 500 | 500 | 150 | TRA |
| 1N1587 | 2 | S1 | 600 | | | | 3.0 | 150 | 1.5 | 500 | 600 | 150 | TRA |
| 1N2072 | 2 | S1 | 50 | 50 | | | .75 | 25A | | 250 | 50 | 100A | TUN |
| 1N2073 | 2 | S1 | 100 | 100 | | | .75 | 25A | | 250 | 100 | 100A | TUN |
| 1N2074 | 2 | S1 | 150 | 150 | | | .75 | 25A | | 250 | 150 | 100A | TUN |
| 1N2075 | 2 | S1 | 200 | 200 | | | .75 | 25A | | 250 | 200 | 100A | TUN |
| 1N2076 | 2 | S1 | 250 | 250 | | | .75 | 25A | | 250 | 250 | 100A | TUN |
| 1N2077 | 2 | S1 | 300 | 300 | | | .75 | 25A | | 250 | 300 | 100A | TUN |
| 1N2078 | 2 | S1 | 400 | 400 | | | .75 | 25A | | 250 | 400 | 100A | TUN |
| 1N2079 | 2 | S1 | 500 | 500 | | | .75 | 25A | | 250 | 500 | 100A | TUN |
| 1N2080 | 1 | S1 | 50 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2081 | 1 | S1 | 100 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2082 | 1 | S1 | 200 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2083 | 1 | S1 | 300 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2084 | 1 | S1 | 400 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2085 | 1 | S1 | 500 | | | | .50 | 25A | .75 | 350 | | 25 | COL |

# CHARACTERISTICS CHART of DIODES and RECTIFIERS

| TYPE NO. | USE (See Code Below) | MAT | PIV (volts) | MAX. CONT. WORK. VOLT. (volts) | Min. Forward Current @ 25°C $I_f$ @ $E_f$ (mA) | (volts) | MAX. D.C. OUTPUT CURRENT[4] (amps) | @ T (°C) | MAX. FULL LOAD VOLT. DROP[4] (volts) | Max. Rev. Current $I_b$ @ $E_b$ @ T (uA) | (volts) | (°C) | MFR. (See code at start of charts) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1N2086 | 1 | Si | 600 | | | | .50 | 25A | .75 | 350 | | 25 | COL |
| 1N2090 | 1,2 | Si | 50 | 50 | | | .75 | .50 | .50 | 250 | 50 | 85 | MAL |
| 1N2091 | 1,2 | Si | 100 | 100 | | | .75 | 50 | .50 | 250 | 100 | 85 | MAL |
| 1N2092 | 1,2 | Si | 200 | 200 | | | .75 | 50 | .50 | 250 | 200 | 85 | MAL |
| 1N2093 | 1,2 | Si | 300 | 300 | | | .75 | 50 | .50 | 250 | 300 | 85 | MAL |
| 1N2094 | 1,2 | Si | 400 | 400 | | | .75 | 50 | .50 | 250 | 400 | 85 | MAL |
| 1N2095 | 1,2 | Si | 500 | 500 | | | .75 | 50 | .50 | 250 | 500 | 85 | MAL |
| 1N2096 | 1,2 | Si | 600 | 600 | | | .75 | 50 | .50 | 250 | 600 | 85 | MAL |
| 1N2115 | 1,2 | Si | 365 | 365 | | | .30 | .50 | .80 | 250 | 365 | 85 | MAL |
| AM7 | 1,2 | Si | 50 | 50 | | | 3.0 | 150 | 1.25 | 500 | 50 | 150 | GIC |
| AM17 | 1,2 | Si | 100 | 100 | | | 3.0 | 150 | 1.25 | 500 | 100 | 150 | GIC |
| AM27 | 1,2 | Si | 200 | 200 | | | 3.0 | 150 | 1.25 | 500 | 200 | 150 | GIC |
| AM37 | 1,2 | Si | 300 | 300 | | | 3.0 | 150 | 1.25 | 500 | 300 | 150 | GIC |
| AM47 | 1,2 | Si | 400 | 400 | | | 3.0 | 150 | 1.25 | 500 | 400 | 150 | GIC |
| AM57 | 1,2 | Si | 500 | 500 | | | 3.0 | 150 | 1.25 | 500 | 500 | 150 | GIC |
| AM67 | 1,2 | Si | 600 | 600 | | | 3.0 | 150 | 1.25 | 500 | 600 | 150 | GIC |
| AM405 | 1,3 | Si | 50 | 50 | | | .150 | 150 | 1.2 | 300 | 50 | 150 | GIC |
| AM410 | 1,3 | Si | 100 | 100 | | | .150 | 150 | 1.2 | 300 | 100 | 150 | GIC |
| AM415 | 1,3 | Si | 150 | 150 | | | .150 | 150 | 1.2 | 300 | 150 | 150 | GIC |
| AM420 | 1,3 | Si | 200 | 200 | | | .150 | 150 | 1.2 | 300 | 200 | 150 | GIC |
| AM425 | 1,3 | Si | 250 | 250 | | | .150 | 150 | 1.2 | 300 | 250 | 150 | GIC |
| AM430 | 1,3 | Si | 300 | 300 | | | .150 | 150 | 1.2 | 300 | 300 | 150 | GIC |
| AM435 | 1,3 | Si | 350 | 350 | | | .150 | 150 | 1.2 | 300 | 350 | 150 | GIC |
| AM440 | 1,3 | Si | 400 | 400 | | | .150 | 150 | 1.2 | 300 | 400 | 150 | GIC |
| AM450 | 1,3 | Si | 500 | 500 | | | .150 | 150 | 1.2 | 300 | 500 | 150 | GIC |
| AM460 | 1,3 | Si | 600 | 600 | | | .150 | 150 | 1.2 | 300 | 600 | 150 | GIC |
| BY501 | 1Ø | Si | 50 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY502 | 1Ø | Si | 100 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY503 | 1Ø | Si | 200 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY504 | 1Ø | Si | 300 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY505 | 1Ø | Si | 400 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY506 | 1Ø | Si | 500 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY507 | 1Ø | Si | 600 | | | | 12 | 120 | 1.5 | 200 | | 25 | BRA |
| BY511 | 3Ø | Si | 50 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY512 | 3Ø | Si | 100 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY513 | 3Ø | Si | 200 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY514 | 3Ø | Si | 300 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY515 | 3Ø | Si | 400 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY516 | 3Ø | Si | 500 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| BY517 | 3Ø | Si | 600 | | | | 12 | 120 | 1.5 | 100 | | 25 | BRA |
| C35A | 5 | Si | 100 | | | | 16 | 80C | .86 | 6500 | | | GE |
| C35B | 5 | Si | 200 | | | | 16 | 80C | .86 | 6000 | | | GE |
| C35C | 5 | Si | 300 | | | | 16 | 80C | .86 | 5000 | | | GE |
| C35D | 5 | Si | 400 | | | | 16 | 80C | .86 | 4000 | | | GE |
| C35F | 5 | Si | 50 | | | | 16 | 80C | .86 | 6500 | | | GE |
| C35G | 5 | Si | 150 | | | | 16 | 80C | .86 | 6500 | | | GE |
| C35H | 5 | Si | 250 | | | | 16 | 80C | .86 | 5500 | | | GE |
| C35U | 5 | Si | 25 | | | | 16 | 80C | .86 | 6500 | | | GE |
| LD70 | 1 | Ge | 12 | 12 | 100 | 1.0 | | | | 100 | 12 | 25 | CBS |
| LD71 | 1 | Ge | 15 | 12 | 2.0 | .40 | | | | 25 | 12 | 25 | CBS |
| LD-70 | 1 | Ge | | 15 | 100 | 1.0 | | | | 150 | 15 | 25A | CBS |
| LD-71 | 1 | Ge | | 15 | 2.0 | .40 | | | | 40 | 15 | 25A | CBS |
| DS203AA | 2 | Si | 50 | | | | 20 | 150C | .75 | 5000 | 50 | 150C | ITT |
| DS203BA | 2 | Si | 100 | | | | 20 | 150C | .75 | 5000 | 100 | 150C | ITT |
| DS203CA | 2 | Si | 150 | | | | 20 | 150C | .75 | 5000 | 150 | 150C | ITT |
| DS203DA | 2 | Si | 200 | | | | 20 | 150C | .75 | 5000 | 200 | 150C | ITT |
| DS203EA | 2 | Si | 250 | | | | 20 | 150C | .75 | 5000 | 250 | 150C | ITT |
| DS203FA | 2 | Si | 300 | | | | 20 | 150C | .75 | 5000 | 300 | 150C | ITT |
| DS203GA | 2 | Si | 350 | | | | 20 | 150C | .75 | 5000 | 350 | 150C | ITT |
| DS203HA | 2 | Si | 400 | | | | 20 | 150C | .75 | 5000 | 400 | 150C | ITT |
| DS203KA | 2 | Si | 500 | | | | 20 | 150C | .75 | 5000 | 500 | 150C | ITT |
| DS203MA | 2 | Si | 600 | | | | 20 | 150C | .75 | 5000 | 600 | 150C | ITT |
| DS203PA | 2 | Si | 700 | | | | 20 | 150C | .75 | 5000 | 700 | 150C | ITT |
| DS203RA | 2 | Si | 800 | | | | 20 | 150C | .75 | 5000 | 800 | 150C | ITT |
| DS303AA | 2 | Si | 50 | | | | 30 | 150C | .75 | 5000 | 50 | 150C | ITT |
| DS303BA | 2 | Si | 100 | | | | 30 | 150C | .75 | 5000 | 100 | 150C | ITT |
| DS303CA | 2 | Si | 150 | | | | 30 | 150C | .75 | 5000 | 150 | 150C | ITT |
| DS303DA | 2 | Si | 200 | | | | 30 | 150C | .75 | 5000 | 200 | 150C | ITT |
| DS303EA | 2 | Si | 250 | | | | 30 | 150C | .75 | 5000 | 250 | 150C | ITT |
| DS303FA | 2 | Si | 300 | | | | 30 | 150C | .75 | 5000 | 300 | 150C | ITT |

# CHARACTERISTICS CHART of DIODES and RECTIFIERS

| TYPE NO. | USE (See Code Below) | MAT | PIV (volts) | MAX. CONT. WORK. VOLT. (volts) | Min. Forward Current @ 25°C $I_f$ @ $E_f$ (mA) | (volts) | MAX. D.C. OUTPUT CURRENT[4] (amps) | @ T (°C) | MAX. FULL LOAD VOLT. DROP[4] (volts) | Max. Rev. Current $I_b$ @ $E_b$ @ T (uA) | (volts) | (°C) | MFR. (See code at start of charts) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DS303GA | 2 | Si | 350 | | | | 30 | 150C | .75 | 5000 | 350 | 150C | ITT |
| DS303HA | 2 | Si | 400 | | | | 30 | 150C | .75 | 5000 | 400 | 150C | ITT |
| DS303KA | 2 | Si | 500 | | | | 30 | 150C | .75 | 5000 | 500 | 150C | ITT |
| DS303MA | 2 | Si | 600 | | | | 30 | 150C | .75 | 5000 | 600 | 150C | ITT |
| DS303PA | 2 | Si | 700 | | | | 20 | 150C | .75 | 5000 | 700 | 150C | ITT |
| DS303RA | 2 | Si | 800 | | | | 30 | 150C | .75 | 5000 | 800 | 150C | ITT |
| DT203AA | 2 | Si | 50 | | | | 20 | 150C | .75 | 5000 | 50 | 150C | ITT |
| DT203BA | 2 | Si | 100 | | | | 20 | 150C | .75 | 5000 | 100 | 150C | ITT |
| DT203CA | 2 | Si | 150 | | | | 20 | 150C | .75 | 5000 | 150 | 150C | ITT |
| DT203DA | 2 | Si | 200 | | | | 20 | 150C | .75 | 5000 | 200 | 150C | ITT |
| DT203EA | 2 | Si | 250 | | | | 20 | 150C | .75 | 5000 | 250 | 150C | ITT |
| DT203FA | 2 | Si | 300 | | | | 20 | 150C | .75 | 5000 | 300 | 150C | ITT |
| DT203GA | 2 | Si | 350 | | | | 20 | 150C | .75 | 5000 | 350 | 150C | ITT |
| DT203HA | 2 | Si | 400 | | | | 20 | 150C | .75 | 5000 | 400 | 150C | ITT |
| DT203KA | 2 | Si | 500 | | | | 20 | 150C | .75 | 5000 | 500 | 150C | ITT |
| DT203MA | 2 | Si | 600 | | | | 20 | 150C | .75 | 5000 | 600 | 150C | ITT |
| DT203PA | 2 | Si | 700 | | | | 20 | 150C | .75 | 5000 | 700 | 150C | ITT |
| DT203RA | 2 | Si | 800 | | | | 20 | 150C | .75 | 5000 | 800 | 150C | ITT |
| DT303AA | 2 | Si | 50 | | | | 30 | 150C | .75 | 5000 | 50 | 150C | ITT |
| DT303BA | 2 | Si | 100 | | | | 30 | 150C | .75 | 5000 | 100 | 150C | ITT |
| DT303CA | 2 | Si | 150 | | | | 30 | 150C | .75 | 5000 | 150 | 150C | ITT |
| DT303DA | 2 | Si | 200 | | | | 30 | 150C | .75 | 5000 | 200 | 150C | ITT |
| DT303EA | 2 | Si | 250 | | | | 30 | 150C | .75 | 5000 | 250 | 150C | ITT |
| DT303FA | 2 | Si | 300 | | | | 30 | 150C | .75 | 5000 | 300 | 150C | ITT |
| DT303GA | 2 | Si | 350 | | | | 30 | 150C | .75 | 5000 | 350 | 150C | ITT |
| DT303HA | 2 | Si | 400 | | | | 30 | 150C | .75 | 5000 | 400 | 150C | ITT |
| DT303KA | 2 | Si | 500 | | | | 30 | 150C | .75 | 5000 | 500 | 150C | ITT |
| DT303MA | 2 | Si | 600 | | | | 30 | 150C | .75 | 5000 | 600 | 150C | ITT |
| DT303PA | 2 | Si | 700 | | | | 30 | 150C | .75 | 5000 | 700 | 150C | ITT |
| DT303RA | 2 | Si | 800 | | | | 30 | 150C | .75 | 5000 | 800 | 150C | ITT |
| FS503AA | 2 | Si | 50 | | | | 50 | 150C | .75 | 10ma | 50 | 150C | ITT |
| FS503BA | 2 | Si | 100 | | | | 50 | 150C | .75 | 10ma | 100 | 150C | ITT |
| FS503CA | 2 | Si | 150 | | | | 50 | 150C | .75 | 10ma | 150 | 150C | ITT |
| FS503DA | 2 | Si | 200 | | | | 50 | 150C | .75 | 10ma | 200 | 150C | ITT |
| FS503EA | 2 | Si | 250 | | | | 50 | 150C | .75 | 10ma | 250 | 150C | ITT |
| FS503FA | 2 | Si | 300 | | | | 50 | 150C | .75 | 10ma | 300 | 150C | ITT |
| FS503GA | 2 | Si | 350 | | | | 50 | 150C | .75 | 10ma | 350 | 150C | ITT |
| FS503HA | 2 | Si | 400 | | | | 50 | 150C | .75 | 10ma | 400 | 150C | ITT |
| FS503KA | 2 | Si | 500 | | | | 50 | 150C | .75 | 10ma | 500 | 150C | ITT |
| FS503MA | 2 | Si | 600 | | | | 50 | 150C | .75 | 10ma | 600 | 150C | ITT |
| FS703AA | 2 | Si | 50 | | | | 70 | 150C | .75 | 10ma | 50 | 150C | ITT |
| FS703BA | 2 | Si | 100 | | | | 70 | 150C | .75 | 10ma | 100 | 150C | ITT |
| FS703CA | 2 | Si | 150 | | | | 70 | 150C | .75 | 10ma | 150 | 150C | ITT |
| FS703DA | 2 | Si | 200 | | | | 70 | 150C | .75 | 10ma | 200 | 150C | ITT |
| FS703EA | 2 | Si | 250 | | | | 70 | 150C | .75 | 10ma | 250 | 150C | ITT |
| FS703FA | 2 | Si | 300 | | | | 70 | 150C | .75 | 10ma | 300 | 150C | ITT |
| FS703GA | 2 | Si | 350 | | | | 70 | 150C | .75 | 10ma | 350 | 150C | ITT |
| FS703HA | 2 | Si | 400 | | | | 70 | 150C | .75 | 10ma | 400 | 150C | ITT |
| FS703KA | 2 | Si | 500 | | | | 70 | 150C | .75 | 10ma | 500 | 150C | ITT |
| FS703MA | 2 | Si | 600 | | | | 70 | 150C | .75 | 10ma | 600 | 150C | ITT |
| FT503AA | 2 | Si | 50 | | | | 50 | 150C | .75 | 10ma | 50 | 150C | ITT |
| FT503BA | 2 | Si | 100 | | | | 50 | 150C | .75 | 10ma | 100 | 150C | ITT |
| FT503CA | 2 | Si | 150 | | | | 50 | 150C | .75 | 10ma | 150 | 150C | ITT |
| FT503DA | 2 | Si | 200 | | | | 50 | 150C | .75 | 10ma | 200 | 150C | ITT |
| FT503EA | 2 | Si | 250 | | | | 50 | 150C | .75 | 10ma | 250 | 150C | ITT |
| FT503FA | 2 | Si | 300 | | | | 50 | 150C | .75 | 10ma | 300 | 150C | ITT |
| FT503GA | 2 | Si | 350 | | | | 50 | 150C | .75 | 10ma | 350 | 150C | ITT |
| FT503HA | 2 | Si | 400 | | | | 50 | 150C | .75 | 10ma | 400 | 150C | ITT |
| FT503KA | 2 | Si | 500 | | | | 50 | 150C | .75 | 10ma | 500 | 150C | ITT |
| FT503MA | 2 | Si | 600 | | | | 50 | 150C | .75 | 10ma | 600 | 150C | ITT |

**NOTATIONS**

Under Use

1 General Purpose
2. Power Rectifier
3. Magnetic Amplifier
Ø Insulated Base
5. Controlled Rectifier

Other

4. For half wave resistive load average over 1 cycle

Under Reverse Current

⊠ Dynamic

Under Mfr.

6. Available in stack form from that manufacturer

Following any temperature reading these symbols apply

A — Ambient
C — Case
J — Junction
S — Storage
△ — Inlet Temperature of Coolant

Type No.

† — Revised Data

Manufacturers should be contacted for value and test condition for surge current and maximum peak recurrent current

# CHARACTERISTICS CHART of DIODES and RECTIFIERS

| TYPE NO. | USE (See Code Below) | MAT | PIV (volts) | MAX. CONT. WORK. VOLT. (volts) | Min. Forward Current @ 25°C $I_f$ @ $E_f$ (mA) | (volts) | MAX. D.C. OUTPUT CURRENT[4] (amps) | @ T (°C) | MAX. FULL LOAD VOLT. DROP[4] (volts) | Max. Rev. Current $I_b$ @ $E_b$ @ T (uA) | (volts) | (°C) | MFR. (See code at start of charts) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FT703AA | 2 | Si | 50 | | | | 70 | 150C | .75 | 10ma | 50 | 150C | ITT |
| FT703BA | 2 | Si | 100 | | | | 70 | 150C | .75 | 10ma | 100 | 150C | ITT |
| FT703CA | 2 | Si | 150 | | | | 70 | 150C | .75 | 10ma | 150 | 150C | ITT |
| FT703DA | 2 | Si | 200 | | | | 70 | 150C | .75 | 10ma | 200 | 150C | ITT |
| FT703EA | 2 | Si | 250 | | | | 70 | 150C | .75 | 10ma | 250 | 150C | ITT |
| FT703FA | 2 | Si | 300 | | | | 70 | 150C | .75 | 10ma | 300 | 150C | ITT |
| FT703GA | 2 | Si | 350 | | | | 70 | 150C | .75 | 10ma | 350 | 150C | ITT |
| FT703HA | 2 | Si | 400 | | | | 70 | 150C | .75 | 10ma | 400 | 150C | ITT |
| FT703KA | 2 | Si | 500 | | | | 70 | 150C | .75 | 10ma | 500 | 150C | ITT |
| FT703MA | 2 | Si | 600 | | | | 70 | 150C | .75 | 10ma | 600 | 150C | ITT |
| SL588 | 2 | Si | 1500 | | 10 | 10 | | | | 100 | 1500 | 25 | TRA |
| SL589 | 2 | Si | 1500 | | 50 | 8.0 | | | | 100 | 1500 | 25 | TRA |
| SL608 | 2 | Si | 800 | | 100 | 1.5 | | | | 20 | 800 | 25 | TRA |
| SL610 | 2 | Si | 1000 | | 100 | 1.5 | | | | 20 | 1000 | 25 | TRA |
| SL612 | 2 | Si | 1200 | | 100 | 1.5 | | | | 20 | 1200 | 25 | TRA |
| SL615 | 2 | Si | 1500 | | 100 | 1.5 | | | | 20 | 1500 | 25 | TRA |
| SL708 | 2 | Si | 800 | | 200 | 1.5 | | | | 20 | 800 | 25 | TRA |
| SL710 | 2 | Si | 1000 | | 200 | 1.5 | | | | 20 | 1000 | 25 | TRA |
| SL712 | 2 | Si | 1200 | | 200 | 1.5 | | | | 20 | 1200 | 25 | TRA |
| SL715 | 2 | Si | 1500 | | 200 | 1.5 | | | | 20 | 1500 | 25 | TRA |
| TJ80A | 2 | Si | 800 | 800 | 400 | 1.5 | 100ma | 100 | 1.5 | 500 | 800 | 150 | TRA |
| TJ100A | 2 | Si | 1000 | 1000 | 400 | 1.5 | 100ma | 100 | 1.5 | 500 | 1000 | 150 | TRA |
| TM55 | 3 | Si | 500 | | 800 | 2.0 | | | | 500 | 500 | 150 | TRA |
| TM56 | 2 | Si | 500 | | 800 | 2.0 | | | | 500 | 500 | 150 | TRA |
| TM65 | 3 | Si | 600 | | 400 | 2.0 | | | | 500 | 600 | 150 | TRA |
| TM66 | 2 | Si | 600 | | 400 | 2.0 | | | | 500 | 600 | 150 | TRA |
| TR501 | 2 | Si | 500 | | | | 10 | 150 | 1.5 | 5000 | 500 | 150 | TRA |
| TR601 | 2 | Si | 600 | | | | 10 | 150 | 1.5 | 5000 | 600 | 150 | TRA |
| ZR20R | 2 | Si | 50 | 50 | | | 8.0 | 25A | 1.2 | 50 | 50 | 25 | FERB-6 |
| ZR21R | 2 | Si | 100 | 100 | | | 8.0 | 25A | 1.2 | 50 | 100 | 25 | FERB-6 |
| ZR22R | 2 | Si | 200 | 200 | | | 8.0 | 25A | 1.2 | 50 | 200 | 25 | FERB-6 |
| ZR23R | 2 | Si | 300 | 300 | | | 8.0 | 25A | 1.2 | 50 | 300 | 25 | FERB-6 |
| ZR24R | 2 | Si | 400 | 400 | | | 8.0 | 25A | 1.2 | 50 | 400 | 25 | FERB-6 |
| ZS50 | 1 | Si | 60 | 60 | | | .20 | 25 | 1.1 | .50 | 60 | 25 | FERB |
| ZS51 | 1 | Si | 60 | 120 | | | .20 | 25 | 1.1 | .50 | 120 | 25 | FERB |
| ZS52 | 1 | Si | 200 | 200 | | | .20 | 25 | 1.1 | .50 | 200 | 25 | FERB |
| ZS53 | 1 | Si | 300 | 300 | | | .20 | 25 | 1.1 | .50 | 300 | 25 | FERB |

**NOTATIONS**

Under Use

1. General Purpose
2. Power Rectifier
3. Magnetic Amplifier
- Ø Insulated Base
5. Controlled Rectifier

Other

4. For half wave resistive load average over 1 cycle

Under Reverse Current

- ☒ Dynamic

Under Mfr.

6. Available in stack form from that manufacturer

Following any temperature reading these symbols apply

- A — Ambient
- C — Case
- J — Junction
- S — Storage
- △ — Inlet Temperature of Coolant

Type No.

- † — Revised Data

Manufacturers should be contacted for value and test condition for surge current and maximum peak recurrent current.

The following manufacturers have announced that they have begun supplying the indicated previously registered diodes and rectifiers.

CBS-Hytron: 1N294
Columbus: 1N440B, 1N441B, 1N442B, 1N443B, 1N444B, 1N547, 1N560, 1N561, 1N1095, 1N1096
International Rectifier Corp: 1N1130, 1N1131
Philco: 1N26, 1N26A, 1N78, 1N78A, 1N78B
Sylvania: 1N128A, 1N191, 1N192, 1N251, 1N252, 1N456, 1N457, 1N458, 1N459, 1N460, 1N461, 1N462, 1N463, 1N464

# PATENT REVIEW*

## Of Semiconductor Devices, Fabrication Techniques and Processes, and Circuits and Applications Jan. 26, 1954 to Nov. 9, 1954

*Compiled by* SIDNEY MARSHALL

**The abstracts appearing in this issue cover the inventions relevant to semiconductors from Jan. 26, 1954 to Nov. 9, 1954. In subsequent issues, patents issued from Nov. 9, 1954 to date will be presented in a similar manner. After bringing these abstracts up to date, PATENT REVIEW will appear every three months, the treatment given to each item being more detailed.**

**January 26, 1954**

2,667,607 Semiconductor Circuit Element—A. L. Robinson. Assignee: Bell Telephone Laboratories. In a circuit element, a pair of outer zones of one conductivity type on opposite sides of and forming *p-n* junctions with an intermediate zone of the opposite conductivity type.

**February 2, 1954**

2,668,262 Asymmetrically Conductive Device—W. C. Dunlap Jr. Assignee: General Electric Company. A device comprising a tubular insulating container, a plurality of spherical semiconductive pellets, a plurality of metallic electrodes each bonded to a relatively large surface area of said pellets to form a plurality of coaxial structures.

**February 16, 1954**

2,669,635 Semiconductive Photoelectric Transducer—W. G. Pfann. Assignee: Bell Telephone Laboratories. A device having *p-n-p* type construction and means for causing light to be absorbed within a distance of no more than one diffusion length from a junction of at least one of the outer zones, said light having a minimum wavelength of 100 Å and a maximum wavelength such that the frequency range corresponds to the average bandwidth of the forbidden region.

2,669,663 Semiconductor Photoconducting Device—J. I. Pankove. Assignee: Radio Corporation of America. A device capable of forming a barrier layer at its surface and having at said surface a semi-transparent film of metal from the class consisting of antimony, bismuth, and beryllium, an electrode in contact with the body, and an electrode in contact with the film.

2,669,692 Method for Determining Electrical Characteristics of Semiconductive Bodies—G. L. Pearson. Assignee: Bell Telephone Laboratories. The method of determining the variation of electrical characteristics of a body of semiconductive material in the direction along which the body which compresses, applying to the body a suspension of dielectric particles in an insulating liquid, and applying a potential between points on the body spaced in said direction.

**February 23, 1954**

2,669,767 Selenium Rectifier—B. P. Hecht, F. Koury. Assignee: Sylvania Electric Products Inc. A method of coating a metal plate with a vitreous layer of selenium, heating the plate to crystallize the selenium layer, exposing the crystallized layer to nascent ozone equivalent to 3 mg. per cubic foot for one and one-half minutes.

2,670,445 Regenerative Transistor Amplifier—J. H. Felker. Assignee: Bell Telephone Laboratories. A device which comprises a flip-flop circuit, a three-terminal transistor, circuit means to trigger the flip-flop circuit and means to provide a regular succession of pulses to the base electrode.

**March 2, 1954**

2,671,156 Method of Producing Electrical Crystal-Contact Devices—R. W. Douglas, A. O. Lindell. Assignee: Hazeltine Research Inc. The method involves passing through a crystalline germanium body and a contact element, including a portion comprising gold maintained in intimate contact with said body, an electric current of a higher order of magnitude than the normal conduction current of the device in order to fuze said contact element to said body.

2,671,189 Semiconductor Amplifier Having a Resiliently Adjustably-Mounted Semiconductor—A. Gaudlitz. Assignee: Siemens & Halske (German Corporation). A semiconductor device comprising a pair of rigid pinlike supporting members, a rigid electrode, a resilient S-shaped spring for carrying a semiconductor on one of its legs, the other leg being fastened to the wall of the device.

**March 16, 1954**

2,672,528 Semiconductor Translating Device—W. Shockley. Assignee: Bell Telephone Laboratories. A device comprising a body of *n*-type material having on one face thereof a zone of *p*-type material, a guard electrode upon said zone, an emitter-base circuit, means for reverse-biasing the collector connection and means for reverse-biasing the guard electrode at a lower potential than the collection.

2,672,580 Semiconductor Device — K. L. Henderson, N. H. Odell. Assignee: Stromberg-Carlson Company. The device is designed to provide a point-contact semiconducting unit in which the electrodes may be automatically and precisely located relative to each other in the process of assembly.

**March 23, 1954**

2,673,311 Crystal Amplifier—S. Amico. Assignee: Sylvania Electric Products Inc. A semiconductor crystal unit comprising a crystal, a back contact thereto, and two catwhisker contacts thereon, and an insulating plate separating the catwhiskers by a distance of the order of 0.002 in.

2,673,312 Semiconductor Device—N. H. Odell. Assignee: Stromberg-Carlson Company. A device having a base and a collector electrode in contact with a semiconductive body, a layer of titanium dioxide covering a portion of the body, and an emitter electrode in contact with said layer.

**March 30, 1954**

2,673,930 Ultrahigh-Frequency Crystal Device of the Asymmetrical Conductivity Type—H. F. Matare. Assignee: Societe Anonymedite: Compagnie des Friens et Signaux Westinghouse. A device comprised of a waveguide, a crystal element, a surface of which is freely exposed to the waves, means of mechanically supporting the crystal, and a flexible point member in contact with the crystal.

2,673,936 Diode Gate—J. R. Harris. Assignee: Bell Telephone Laboratories. The device is designed to decrease the *d-c* power drain in electronic gating circuits, to decrease the peak power gain imposed on the control voltage source by the gating circuit itself, and to permit use of a control voltage source having a low power output capability and low *d-c* power drain.

2,673,948 Crystal Device For Controlling Electric Currents By Means of a Solid Semiconductor—H. F. Matare, H. Welker. Assignee: Societe Anonymedite: Compagnie des Friens et Signayx Westinghouse. A multi-electrode crystal device for producing electronic relay action.

**April 13, 1954**

2,675,433 Degenerative Amplifier — J. I. Pankove. Assignee: Radio Corporation of America. A device designed to provide a degenerative amplifier where the amount of degeneration may be adjusted to suppress either partially or entirely a predetermined polarity of the input signal.

2,675,474 Two-Terminal Sine Wave Oscillator—E. Eberhard. Assignee: Radio Corporation of America. A transistor device having an impedance element between the base and a point of fixed potential, a resistor between the emitter and said point, a series resonant circuit con-

* Source Official Gazette of the U. S. Patent Office, and Specifications and Drawings of Patents Issued by the U. S. Patent Office.

nected across the resistor, and means for deriving a sinusoidal output wave across the inductance element.

2,675,477 Modulator for Pulse Transmitters —S. Teszner. Assignee: None. A modulator for generating high-voltage pulses of substantially rectangular wave-shape for a pulse transmitter.

**April 20, 1954**

2,676,228 Conditioning of Semiconductor Translators—J. N. Shive. Assignee: Bell Telephone Laboratories. The method of permanently altering the electrical characteristics of a light responsive translator which comprises liberating minority charge carriers in the body in the vicinity of the collector by applying light to the region simultaneously with the application of electrical forming energy to the collector.

2,676,271 Transistor Gate—E. G. Baldwin. Assignee. Bell Telephone Laboratories. An electronic circuit designed to controllably gate an input signal and at the same time amplify the signal being gated, and to increase the *off/on* loss ratio of a transmission type gate.

2,676,288 Rectifier Assembly and Cooling Means Therefor—J. J. Riley. Assignee: The Taylor-Winfield Corporation. A stack assembly in which the plates have axially aligned apertures, tubular rods inserted in these apertures, and manifold plates secured to each end of said tubular rods and having fluid passages therein communicating with the interior of said rods.

**April 27, 1954**

2,677,106 Testing of Semiconductors—J. R. Haynes, J. A. Morton. Assignee: Bell Telephone Laboratories. The method of comparing bodies of semiconductive material with respect to intrinsic lifetime which comprises treating a smooth surface of the body to reduce the recombination velocity, generating mobile charge carriers in a striplike portion, detecting said carriers at a fixed place on the surface, and indicating the rate at which the concentration varies with the separation between the strip and the point of detection.

**May 4, 1954**

2,677,793 Crystal Amplifier—F. Koury. Assignee: Sylvania Electric Products, Inc. A semiconductor device having a large area contact, a conductor in point-contact with the semiconductive crystal, an insulating coating over the surface of said conductor and a metallic layer over the insulating coating.

**May 25, 1954**

2,679,584 Detector — A. A. MacDonald. Assignee: Westinghouse Electric Corporation. A linear detector circuit comprising an input circuit that utilizes a pair of similar crystal rectifier units.

2,679,594 Wave Generator—K. N. Fromm. Assignee: Westinghouse Electric Corporation. A pulse generator comprising a transistor, means for causing collector output power to be fed back to the emitter, and an external network interconnecting the base, emitter and collector.

2,679,619 Controlled Semiconductor Rectifier—L. Grassl. Assignee: Siemens & Halske (German Corporation). A rectifier comprising a cylindrical tubular body of semiconducting material, a large contact area base electrode, and two additional electrodes comprising a plurality of knife-edge elements each having said edge in axially extending engagement with the outside of the semiconductive body.

**June 1, 1954**

2,680,159 Amplifier Employing Semiconductors—E. H. Grover. Assignee: International Standard Electric Corporation. A body of semiconductive material divided nearly in two, a collector and emitter electrode, and two base electrodes in contact with the two portions, and means for biasing the collector and emitter electrodes with respect to the base electrodes so that the collector and emitter currents are constrained to flow in the same part of the narrow portion of the U-shaped body.

2,680,160 Bias Circuit For Transistor Amplifiers—R. E. Yaeger. Assignee: Bell Telephone Laboratories. The circuit is designed to provide a transistor biased for high or maximum power dissipation while having a stabilized operating point, and to provide a stably adjusted amplifier whose base current varies widely percentagewise with temperature.

2,680,220 Crystal Diode and Triode—A. T. Starr, C. DeBoismaison, N. S. Cinderey, K. A. Matthews, R. B. Cooke. Assignee: International Standard Electric Corporation. A point-contact electric amplifying device comprising a semiconductive disc covered by a metal film that serves as a base electrode, on the other face a perforated insulating film, a metal film electrode of area greater than $10^{-4}$ square millimeter and less than 1 square millimeter, and a catwhisker electrode making point-contact with the semiconductor.

**June 22, 1954**

2,681,993 Circuit Element Utilizing Semiconductive Materials—W. Shockley. Assignee: Bell Telephone Laboratories. A signal translating device comprising a body of semiconductive material having a first and a third zone of one conductivity type and a second zone of the opposite type, intermediate and contiguous with the first and third zones, an input circuit to zone 1 and 2, and a feedback coupling between zone 3 and the input circuit.

2,681,996 Transistor Oscillator—R. L. Wallace. Assignee: Bell Telephone Laboratories. A circuit comprising a non-linear resistance element having a negative temperature coefficient interconnecting the transistor base electrode with an intermediate tap of an inductance winding, and a series-tuned resonant circuit shunting a portion of said winding.

2,682,002 Transformerless Voltage Multiplier Circuits—V. R. Gibson Jr. Assignee: General Electric Company. A power supply circuit adapted to produce a plurality of direct current potentials that are integrals of a fundamental direct component of a source of alternating-current potential having one side established at a reference potential.

2,682,022 Metal-Envelope Translator—R. F. Doran. Assignee: Sylvania Electric Corporation. An hermetically sealed unit composed of a point-contact device, a semiconductive body, a metallic tubular envelope enclosing the unit, and a coaxial assembly supporting the point-contact element.

2,682,034 Apparatus for Applying High Intensity Electrical Pulses to Crystal Rectifiers—H. C. Torrey, J. B. Weisner. Assignee: United States of America (Navy Department). The unit comprises a transmission line composed of two conductors having the same impedance as the electrical device, a voltage source for charging said line, and means for rapidly moving one conductor in a direction to connect conductively said electrical device across said transmission line.

**June 29, 1954**

2,682,640 Arrangement For Modulating Electric Carrier Wave Oscillations—D. W. Harling. Assignee: General Electric Company Ltd. An arrangement comprising a cathode follower, a bridge modulator circuit, a carrier wave oscillation generator, and means for connecting the bridge modulator across the output terminals of the cathode follower.

**July 6, 1954**

2,683,204 Circuits for Welding Semiconductor Devices—J. F. Roach. Assignee: Hughes Aircraft Company. An electrically annealed circuit for producing an electrical weld first between the crystal and catwhisker elements of a first semiconductor device, and then performing the same operation on a second semiconductor device.

2,683,205 Machine For Making Crystal Rectifiers and the Like—B. J. Yanchenko. Assignee: General Electric Company. A machine for inserting a pair of electric terminal assemblies into a casing and effecting a weld between said assemblies.

**July 13, 1954**

2,683,794 Infra-Red Energy Source—H. B. Briggs, J. R. Haynes, W. Shockley. Assignee: Bell Telephone Laboratories. The method of generating infra-red energy in a narrow band width that comprises passing a current of at least 10 amperes per square centimeter across a semiconductive *n-p* junction in the forward direction of conduction.

2,683,794 Pulse Generator—K. N. Fromm. Assignee: Westinghouse Electric Corporation.

2,683,840 Semiconductor for Control Purposes — H. Welker. Assignee: Societe Anonymedite: Compagnie des Friens et Signaux Westinghouse. A device having a thin semiconductive layer, emitter, and collector electrodes; and a control electrode arranged in the gap between the emitter and the collector and electrode extending parallel to said layer, and in contact therewith.

2,683,853 Power Transmission — F. G. Logan. Assignee: Vickers Incorporated. A magnetic amplifier comprising a reactor, means for passing intermittent unidirectional pulses through the reactor winding, a path for passing intermittent current through said winding in the opposite direction, and means for opposing the passage of this latter current.

2,683,854 Power Transmission—J. R. Conrath. Assignee: Vickers Incorporated. A magnetic amplifier comprising power input and output circuits and means for controlling the flow of power between the input and output circuits.

**August 10, 1954**

2,686,279 Semiconductor Device—L. E. Barton. Assignee: Radio Corporation of America. Preparation of the device includes grinding a germanium crystal to

obtain a plane surface, removing grinding marks by electrochemical means thus oxidizing the prepared surface, positioning two point contact electrodes and a large area electrode, and then passing D.C. pulses from a point contact electrode to the large contact area electrode.

**August 31, 1954**

2,688,110 Semiconductor Translating Device—J. V. Domaleski, E. L. Gartland, J. J. Kleimak. Assignee: Bell Telephone Laboratories. A seamless hollow insulating envelope surrounding a semiconductive body and engaging and securing in the proper position the electrodes attached thereto, said envelope having a cavity containing an electrode with a flexible portion and a yieldable nonconducting material surrounding the flexible section.

**September 21, 1954**

2,689,930 Semiconductor Current Control Device—R. N. Hall. Assignee: General Electric Company. A device comprising a crystal having adjoining *p*-type and *n*-type zones, an acceptor activator electrode fuzed to the *p*-type surface region and a donor activator electrode fuzed to the *n*-type region.

**October 5, 1954**

2,691,070 Transistor System for Translating Signals in Two Directions—R. V. Lowman. Assignee: Hazeltine Research Inc. A system for translating signals in two directions comprising a transistor, a high impedance first terminal circuit and low impedance signal translating channels, a similar second terminal circuit, and an A-C source of bias potential connected to said circuits to render the transistor conductive alternately in opposite senses, and to control the nonlinear elements in said circuits in order to translate signals in two directions between said circuits.

2,691,074 Amplifier Having Frequency Responsive Variable Gain—E. Eberhard. Assignee: Radio Corporation of America. A device consisting of a three terminal transistor, parallel resonant input and output circuits, and a series resonant circuit connected between the emitter and the input circuit so as to render the gain of the amplifier a function of the frequency of the input signal.

2.691,075 Transistor Amplifier With High Undistorted Output—R. F. Schwartz. Assignee: Radio Corporation of America. The device is designed to provide a single-ended push-pull transistor amplifier utilizing two transistors of different electrical characteristics which provides a high undistorted output.

2,691,076 Semiconductor Signal Translating System—A. R. Moore, F. Herman. Assignee: Radio Corporation of America. In a translating system, two semiconductors having a barrier and each capable of providing a potential gradient thereacross, means for causing a modulated electron beam to impigne upon the bodies near the barriers, means for deriving an output signal across load impedance elements.

2,691,077 Transistor Power Amplifier—L. L. Koros. Assignee: Radio Corporation of America. The device is designed to provide a transistor amplifier which provides negligible distortion of the signal to be amplified, and to provide a circuit having constant current input thereby reducing inherent distortion to a minimum.

**October 12, 1954**

2,691,577 Alloys and Rectifiers Made Thereof—K. Lark-Horovitz, R. M. Whaley. Assignee: Purdue Research Foundation. An alloy having semi-conducting properties and consisting essentially of germanium and titanium in an amount up to 0.5 atomic percent.

2,691,736 Electrical Translation Device Including Semiconductor—J. R. Haynes. Assignee: Bell Telephone Laboratories. In this device means for supplying signal current controlled mobile charge carriers, a region of the semiconductor body removed from the emitter area, a second region surrounding the emitting means such that the mobile charge carrier decay rate for the first region is at least ten times greater than the rate in the second region.

2,691,750 Semiconductor Amplifier—J. N. Shive. Assignee: Bell Telephone Laboratories. An amplifier comprising a wafer of *n*-type semiconductor, and an emitter collector, and base connection.

**October 19, 1954**

2,692,337 Oscillation Generator—R. L. Hanson. Assignee: Bell Telephone Laboratories. A semiconductor device having three impedance elements connecting the emitter collector, and base respectively to a ground point, and a feedback path directly connecting the collector and emitter electrodes.

2,692,343 Pulse Separating Circuit—S. J. Spiro. Assignee: Stewart-Warner Corporation. A pulse separating circuit for eliminating from a train of pulses the first pulse of a group.

**October 26, 1954**

2,692,839 Method of Fabricating Germanium Bodies—H. Christensen, G. K. Teal. Assignee: Bell Telephone Laboratories. A method of forming a layer of germanium upon a body of germanium which comprises treating said body with a gaseous mixture of hydrogen, germanium halide, and an impurity determining a conductivity type opposite to that of said body.

2,692,950 Valve for Infra-Red Energy—R. L. Wallace. Assignee: Bell Telephone Laboratories. The method of modulating light having a wavelength greater than 1.2 microns which comprises passing the light through a silicon body injecting free charge carriers into the body and modulating the rate of carrier injection.

2,692,952 Semiconductive Light Valve—H. B. Briggs. Assignee: Bell Telephone Laboratories. A valve comprising a semiconductive body that is normally transparent to light of greater than a threshold wavelength, means for optically controlling the beam within the body, and means for injecting free charge carriers into the body.

**November 2, 1954**

2,693,022 Method of Manufacturing Whisker Electrodes—A. M. Gurewitsch, W. C. Dunlap Jr. Assignee: General Electric Company. A method for establishing a sharp pointed single fine wire strand comprising surrounding the wire with a thick metallic layer, severing the assembly at an acute angle to the longitudinal axis, and dissolving the metallic coating.

2,693,555 Method and Apparatus for Welding Germanium Diodes—H. Q. North, S. H. Barnes, J. F. Roach. Assignee: Hughes Aircraft Company. A method of welding a metallic electrode to a germanium crystal element which produces a two-electrode device, one electrode of which makes contact with the crystal by means of a non-rectifying welded connection.

2,693,556 Semiconductor Diode—P. J. Gahagan. Assignee: None. A crystal point-contact diode comprising a cylindrical envelope of ceramic tubing, a pair of spaced metallic members partially within the envelope, and a thermosetting resin in said envelope surrounding and mechanically bonding the elements therein.

2,693,568 Current and Voltage Regulation—F. H. Chase. Assignee: Bell Telephone Laboratories. In a two-transistor circuit, means for impressing upon the emitter of one transistor a potentional with respect to the base having variations corresponding to load voltage changes, and means for impressing between the base and emitter of the other transistor a voltage for controlling the current supplied to the load.

2,693,572 Current and Voltage Regulation—F. H. Chase. Assignee: Bell Telephone Laboratories. An objective of this device is to provide a circuit including a transistor and a Zener diode for setting up a control voltage and having means for reducing or eliminating voltage changes due to changes of ambient temperature.

**November 9, 1954**

2,694,024 Semiconductor Bodies for Signal Translating Devices—W. L. Bond, M. Sparks, G. K. Teal. Assignee: Bell Telephone Laboratories. A silicon or germanium rod consisting of two longitudinal *n*-type crystals having orientations differing by about ten degrees, said crystals being physically continuous across an intervening region of *p*-type conductivity, the (III) crystal planes being transverse to the rod.

2,694,113 Transistor Amplifier With Conjugate Input and Output Impedances—L. A. Meacham. Assignee: Bell Telephone Laboratories. A transistor circuit having a voltage divider impedance element connecting the base and the collector, an intermediate tap on said element, a series input circuit, and an output circuit including a load in shunt with said impedance element.

2,694,115 Push-Pull Transistor Amplifier With Conjugate Input and Output Impedances—L. A. Meacham. Assignee: Bell Telephone Laboratories. A circuit designed to provide strictly one way amplification of signals, to render the input impedance of the amplifier circuit independent of its load, and to render the output impedance independent of the driving source.

2,694,168 Glass-Sealed Semiconductor Crystal Device—H. Q. North, J. N. Carman Jr. Assignee: Hughes Aircraft Company. A device sealed in a hollow glass cylinder and comprising an *n*-type multifaced germanium element, a copper layer bonded to one face of said element, a silver layer bonded to the copper, a lead wire, and a conductive vitreous bond between the wire and the silver layer.

Continued in
May Issue

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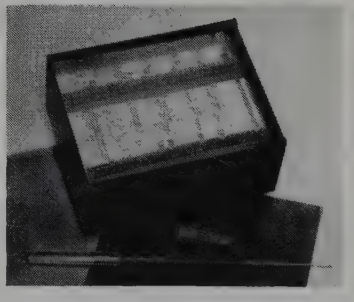
## TRANSISTOR INDEX



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# New Products

**Silicon Photo-Duo-Diode**

Availability of a new subminiature light-sensing photo-duo-diode 1N2175 was announced recently by Texas Instruments. This diffused N-P-N diode allows current flow when either junction is exposed to light, but shuts current off in darkness. Sensitivity combined with subminiature size makes it ideal for applications such as reading of data from punched tape and card systems. Single-ended glass case measures 0.500" by 0.085". A minute glass lens is located at the end opposite the leads. Passes up to 1200 microamps when exposed to 1200 foot-candles of light. In darkness, it will pass less than 0.5 microamps. Dissipation is rated at 250 milliwatts at 25°C.

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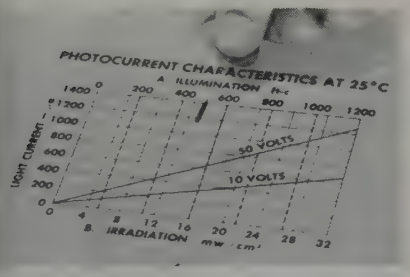


**Transistorized Power Supplies**

By means of a few simple external connections, Electronic Measurements voltage regulated power supplies may be used for constant current operation. Wide range models cover the following voltage ratings: 0-7, 0-14, 0-32, 0-36, 0-60. Narrow range models cover all popular battery voltages up to 60. Most models are available in current ratings of 0-2.5A, 0-5A, 0-7.5A, 0-10A, and 0 to 15A.

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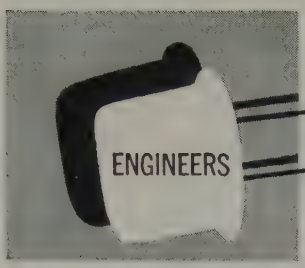


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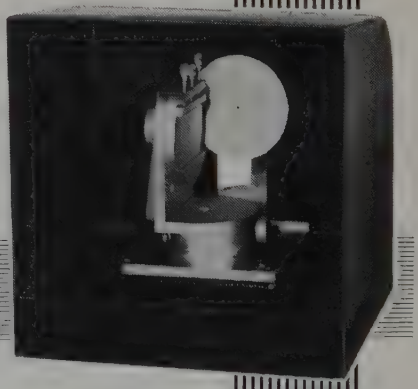

**EFFICIENT.** Visual undistorted pattern allows immediate adjustment. Requires no interpretation or correlation with charts and data.

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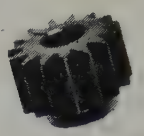
Keep transistors at or below maximum operating temperatures with these new Birtcher Transistor Radiators. Provides the transistor with its own heat sink and a greatly increased radiating surface. Easy to install in new or existing equipment. Modifications to fit hundreds of popularly used transistors.



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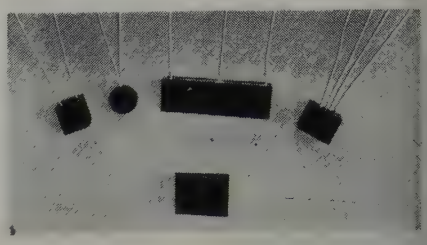
**Miniature Selenium Rectifiers**

Designed to meet applications in which space is limited, a new, miniature line of completely potted selenium rectifiers, known as the ABC series, is available from General Instrument Corporation's Radio Receptor Division. Available in a wide range of voltages and currents for use in half wave, full wave, single or three-phase rectifier circuits. Dimensions depend upon specific voltage and current requirements.

Circle 130 on Reader Service Card



**Transistor Test Rotor**

Lourdes Instrument Corporation, manufacturers of a complete line of superspeed centrifuges, announces the development of a special rotor designed specifically for subjecting transistors, diodes and other semiconductors to a centrifugal acceleration of from 10,000 to 25,000 times gravity. The application of such force is often required by military specifications and may also be included in an overall testing program, together with vibration, impact, corrosion and temperature tests.

Circle 141 on Reader Service Card

**Transistor Satellite Transmitter**

An all-transistor 20 megacycle telemetering transmitter, designed for possible use in space satellites, has been built by Philco Corporation for the U. S. Army. It weighs less than 10 ounces, is five inches in diameter and one inch high, and is capable of operating at high efficiency in outer space within a temperature range of 5 to 187°F. Consists of 3 sections: Oscillator, Power Amplifier, and Modulator.

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**ubminiature Bridge Rectifier**
A new series of subminiature silicon idge rectifiers extends the International ectifier line to replace bulky vacuum be bridge rectifiers in 1/50 of the volume d weighing less than 1/100 of equivalent be circuitry. Measuring 0.875 x 0.719 x 750", weighing ¼ ounce, these rugged, ock-resistant devices are designed pri-arily to provide extreme miniaturization missile, airborne and ground system rcuitry, and may be operated at tem-eratures up to 165°C. Request Bulletin R-207.
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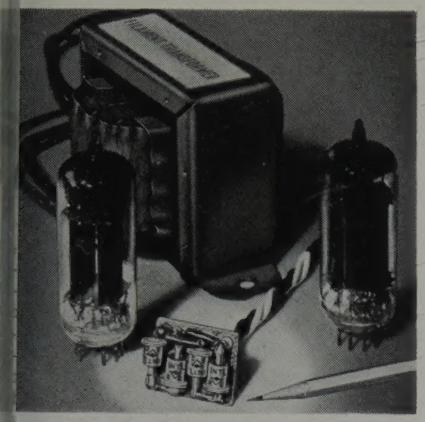
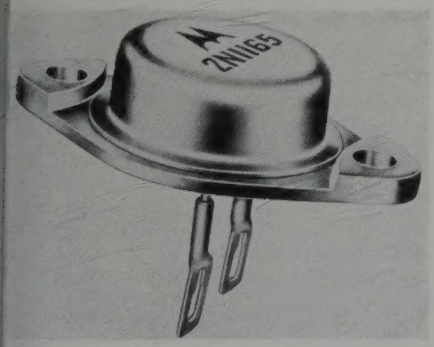
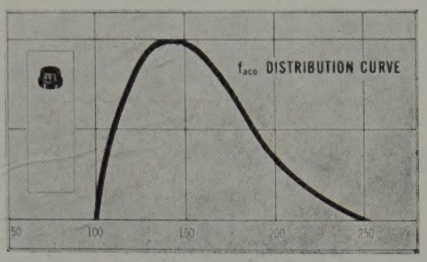


**ower Transistor Line**
Featuring 25 amperes D. C. collector urrent, the new line of power transistors y the Semiconductor Division of Mo-orola has exceptionally high current as well as good Beta linearity. Numbered N1162 through 2N1165, these units are ermanium PNP, alloy junction types, with collector common to the case. De-igned for high current switching and udio applications, featuring rugged in-ernal design and hermetically sealed tandard TO-3 package. Available with or without solder terminals.
Circle 135 on Reader Service Card




**Mercury Battery Packs**
Small mercury battery cells were used to power the transmitting and other recording devices of the Satellite launched from the Navy's Vanguard Rockets. This mercury battery power unit comprised a cluster of batteries with a multi-prong plug potted in Eccofoam. The mercury battery packs, developed and manufactured by Mallory Battery Co., a Division of P. R. Mallory & Co., are the same type used to provide energy for the electronic reporting equipment in previous U. S. satellites. The complete electronic and battery component, which will transmit a constant tracking signal as the satellite makes its orbit at 18,000 miles an hour, weighs 13 pounds. The transmitter will send signals back to earth from outer space.
Circle 143 on Reader Service Card

**Logic Silicon Transistor**
Transitron Electronic Corporation announces availability of silicon logic transistors with the speed of the fastest germanium types. The new transistor 2N1139, with its speed and power handling abilities, represents great progress in transistor technology. Typical total switching times average less than 30 millimicroseconds. Guaranteed Alpha cutoff of 100 mc minimum. Write for Bulletin PB13.
Circle 131 on Reader Service Card




**Double Anode Zener Diode**
U.S. Semiconductor Products announces a medium power double anode silicon zener diode for clipping, pulse forming, and voltage regulating applications with lower Tc. Offered in same small packages available in Semcor's standard medium power line. Zener voltages from 7½v to 35v, .038% to .066% per °C Tc. Diffused junction techniques provide commercial and military users with reliable performance diodes for their applications.
Circle 152 on Reader Service Card

**Crystal Orientation Device**
Sylvania has announced the development of a new measuring instrument which assures rapid and accurate orientation of silicon and germanium crystals used in the manufacture of transistors, diodes, and other semiconductor devices. It utilizes a converging beam of light projected upon microscopic etch pits in the surface of the material. The beam is reflected from the facets of the etch pits and split into a number of component rays equal to the number of planes comprising a single pit. The planes behave like tiny mirrors which reflect these component rays to a screen in the form of a light pattern which can be interpreted by the operator immediately as to orientation.
Circle 133 on Reader Service Card

**Flux Quantizing Time Base and Divider**
A new line of solid state decade dividers announced by the Burroughs Corp. is designed to provide accurate frequency dividing or timing pulses up to 100 kc with the minimum of components, size, and power consumption. Counting is accomplished by the use of two miniature tape wound cores and two transistors. This new technique uses two cores known as the "quantizing core" and the "counting core." The "quantizing core" develops a standardized pulse to drive the "counting core" which will accumulate 10 counts before an output pulse is obtained. Variable division ratios other than 10 can be obtained by minor modification.
Circle 146 on Reader Service Card

**Digital Voltmeter**
Franklin Electronics announces a new general-purpose digital voltmeter, covering a range of 0 to 1000 V dc. The new instrument, designated Model 410, utilizes an all-electronic circuit and provides an accuracy better than 0.5% of full scale. A three-column, vertical readout is used.
Circle 151 on Reader Service Card

**Transistorized Electronic Switch**
Navigation Computer Corp. announces a new completely transistorized Electronic Switch, Model 129A, which has been added to the standard line of NAVCOR digital system building blocks, and performs the following functions: (1) gating of pulse bursts, (2) standardizing pulses to the NAVCOR system −Vk pulse, and (3) providing a "one-shot gate" circuit. It is a standard NAVCOR slide-in module measuring 2¼" high, 10¾" wide and 7" deep.
Circle 154 on Reader Service Card

**Tiny Guided Missile Capacitor**
A tiny molded mica capacitor to make possible smaller, lighter guided missiles has been developed by General Instrument subsidiary, Micamold Electronic Mfg. Corp. The Subminiature "Missilmite" operates at broadest humidity and temperature extremes and permits great design flexibility to the engineer. The device is claimed to withstand operating temperatures of −55°C to +125°C. Can also be used in delay lines, pulse networks, computers, transistorized assemblies. etc.
Circle 134 on Reader Service Card

**Casting Resin Absorber**
Emerson & Cuming has introduced a new product designated Eccosorb CR. It is a casting resin which can be used to mold to size waveguide terminations, attenuators and loads. When cured, it has high attenuation over the full microwave frequency range. It is supplied as a two-component liquid system. When properly proportioned and cast, the material can be cured to a rigid plastic which will reproduce mold dimensions accurately. It can then be readily machined, if required. Cure can be accomplished at room temperature or rapidly at elevated temperature. Both step-tapered and uniform-tapered loads can be produced.
Circle 148 on Reader Service Card

**DC/AC Power Supply**
A new compact DC/AC power supply named the "Handivolt" has been announced by Nutron Manufacturing Co. Features high power, small size, high efficiency at all voltage settings, smooth stepless control and choke type filter for low ripple content. Manufactured in many voltage and amperage combinations to handle every laboratory and electronic problem. Series B units are isolated from line and have a voltmeter to monitor DC voltage output. All models are rated for heavy duty. Variable AC output is brought out to line receptacle. Low voltage models have 2 variable AC outlets.
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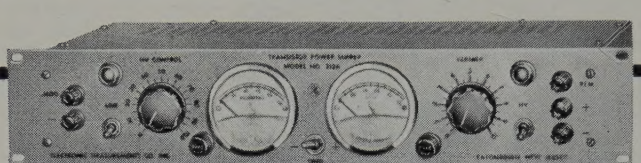
# 1 *REGATRON POWER SUPPLY DOES THE WORK OF 3 ORDINARY POWER SUPPLIES

**a case history**



(Model 212AM:
0-100 V dc, 0-100 ma,
$129.00 unmetered)

A MANUFACTURER required three different regulated voltages. The voltages, which were to be used alternately, could be furnished by three separate power supplies or by a single power supply and a voltage divider. But, three power supplies were expensive. On the other hand, a voltage divider meant a loss of power and regulation plus the expense of high-wattage components.

THE SOLUTION: Three 1-watt resistors and a *Regatron Programmable Power Supply. An exclusive programming feature permits changing output voltage by shunting two terminals with a resistor. For each 1000 ohms, the Regatron delivers one volt . . . at rated current and regulation.

IN THE PROBLEM quoted here, the required voltages were 14.5, 28, and 45 V dc. The three resistors were 14.5K, 28K, and 45K. Regatron Programmable Power Supplies are available in many ranges up to 600 V dc and 3 amperes. Bulletin 765A tells more about how Programmable Regatrons solve d-c problems. Write for your copy.

**POWER FACT No. 5** — **Regulation:**

Regulation would appear to be a simple operating characteristic of a power supply. Yet much confusion exists concerning the exact meaning of the word. Relative regulation, absolute regulation, etc. are different aspects which are often confused.

For definitions and a useful discussion of these matters, send for Technical Bulletin No. 2005. It is free of charge.

*Registered U.S. Patent Office. U.S. Patents Issued and Pending.

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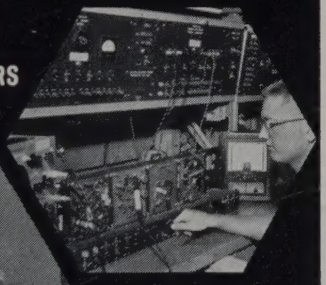
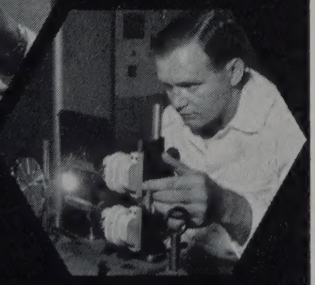


ELECTRONIC ENGINEERS

PHYSICAL CHEMISTS



SOLID STATE PHYSICISTS

ELECTRONIC ENGINEERS at TI's Semiconductor-Components division are beating the heat barrier with devices operating at 200°C and higher — twice the boiling point of water! Under the hot glare of infrared light simulating extreme operating conditions, the engineer shown above is testing a TI-introduced silicon power transistor operating in conjunction with the new *Sensistor* temperature-compensating silicon resistor.

Exploration of new frontiers in solid state electronics is a never-ending project at TI's S-C division with engineers, physicists and chemists combining their research efforts to extend frequency, power and temperature limits — building America's electronic future. If you are interested in joining other leading engineers and scientists at the industry's most modern research, development and production facilities — write or call for more information on Texas Instruments, a corporation nearly three decades old — recognized leader of the semiconductor industry.

Inquiries from experienced graduate engineers interested in furthering solid state electronic technology are welcomed by the TI Semiconductor-Components division. You can play a vital role in research or development engineering on:

**transistors, diodes, rectifiers, capacitors, resistors, IR detector cells, materials purification, circuit design and application, test equipment design, and design of complex automatic machinery.**

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Whether you're designing audio circuits or switching circuits, you'll get a true picture of operating parameters minutes after you've drawn the circuit diagram . . . without wasting valuable time with breadboard and soldering gun.

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An ideal laboratory instrument, Transimulators are inexpensive enough to justify several on every bench. You can even use the LF-1 to test transistors *in the circuit* . . . the only real proof of design parameters. And a complete step-by-step instruction manual makes operation fast, simple, and easy.

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- RANGE—Audio, up to 100 kc.
- TRANSISTOR POWER—Through medium power audio output.
- BATTERY SUPPLY.—Separate bias and load. 1.5, 3, 4.5, 6 volts d-c. Polarity Reversing Switch.
- COUPLING—2 $\mu$f and 20 $\mu$f Direct, and Ext. C. posts, on both Input and Output.
- BIAS RESISTANCE—Up to 555,000 ohms continuously variable.
- LOAD RESISTANCE—Up to 277,500 ohms continuously variable.
- EMITTER RESISTANCE—Up to 2,500 ohms variable. Series resistor and bypass capacitor can be added.
- BASE COLLECTOR STABILITY—Up to 250,000 ohms variable. Series resistor and bypass capacitor can be added.
- VOLTAGE DIVIDER STABILITY—Up to 50,000 ohms variable.
- 5-WAY BINDING POSTS—For meters, transformer coupling, external supply voltage, degeneration, bypass, coupling, signal input and output, almost any connection required.

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